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Survey of smart grids concepts worldwide

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Abstract

The objective of this report is to compile various smart grid concepts, architectures and details of associated technologies implemented worldwide. The survey is based on initiatives taken by EU and IEA (e.g. ETP, EEGI, EERA and IEA DSM) and description of projects conducted in Europe and US (e.g. FENIX, ADDRESS, EU-DEEP, ADINE, GridWise and SEESGEN-ICT). The report presents drivers, visions and roadmaps to develop smart grids in US, China and India. The survey encompasses various smart grid concepts, i.e. development of virtual power plant, active demand in consumer networks, DER aggregation business, active distribution network and ICT applications to develop intelligent future grids.

The comparison is carried out on the basis of commercial, technological and regulatory aspects. In addition, the existing features of smart grid technology and challenges faced to implement it in Finnish environment are addressed. As a matter of fact, the implementation of smart grid is consisting of more than any one technology, therefore, this transition will not be so easy. In the end, a fully realised smart grid will be beneficial to all the stakeholders. Smart grid is an evolution towards an optimised and sustainable energy system which is more intelligent, efficient and reliable and it has positive influence on the climate change.

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Preface

The survey was conducted as an activity of SGEM (the Smart Grid and Energy Markets) project mainly funded by TEKES (The Finnish Funding Agency for Technology and Innovations). The survey was carried out as one of the tasks of WP1.3: Migration scenarios towards future Smart Grids (phase I). The aim of the SGEM research program (2010–2014) is is to develop international Smart Grid solutions that can be demonstrated in a real environment utilising Finnish research, development and information infrastructure. At the same time, the benefits of an interactive international research environment will accumulate know-how of the world-leading ICT and smart grid providers.

The SGEM coordinator is CLEEN Oy (Cluster for Energy and Environment) which is the strategic centre for science, technology and innovation of the Finnish energy and environment cluster. CLEEN Oy was established in the year 2008 to facilitate and coordinate world class industry driven research in the field of energy and environment. The SGEM consortium consists of industrial and research partners. The industrial partners are ABB Oy, Aidon Oy, Alstom Grid Oy, Cybersoft, Elektrobit, Empower Oy, Emtele Oy, Fingrid Oy, Fortum Säkkoönsiirto Oy, Helen Sähköverkko Oy, Nokia Siemens Networks Oy, Suur-Savon Sähkö, Tekla Oy, Telia Sonera, The Switch Drive Systems Oy, There Corporation, Vantaan Energia Sähköverkot Oy, Vattenfall Verkko Oy and Viola Systems. The research partners are Aalto University, Lappeenranta University of Technology, MIKES, Tampere University of Technology, University of Eastern Finland, University of Oulu, University of Vaasa and VTT.

Espoo, March 2011

Author

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List of abbreviations

AC	Alternating Current
ADDRESS	Active Distribution network with full integration of Demand and distributed energy RESourceS
ADINE	Active DIstribution NEtwork
AMI	Advanced Metering Infrastructure
AMR	Automated Meter Reading
ANM	Active Network Management
AVR	Automatic Voltage Regulator
BPL	Broadbnad over Power Lines
CHP	Combined Heat and Power
CVPP	Commercial Virtual Power Plant
DC	Direct Current
DER	Distributed Energy Resources
DG	Distributed Generation
DMS	Distribution Management System
DNP	Distributed Network Protocol
DR	Demand Response
DSM	Demand Side Management
DSO	Distribution system operator
EB	Energy Box
EC	European Commission
EEGI	European Electricity Grid Initiative
EERA	European Energy Research Alliance
EPRI	Electric Power Research Institute
ESCO	Electric Supply Company
ETP	European Technology Platform
EU	European Union
EU-DEEP	The birth of EUropean Distributed EnErgy Partnership
EV	Electric Vehicle
FENIX	Flexible Electricity Network to Integrate the eXpected energy evolution
GDP	Gross Domestic Product
GPRS	Global Packet Radio Service
GPS	Global Positioning System
GW	Giga Watts
HAN	Home Area Network
HVAC	High Voltage Alternating Current

HVDC	High Voltage Direct Current
ICT	Information and Communications Technology
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IP	Internet Protocol
IT	Information Technology
kV	kilo Volts
LV	Low Voltage
MV	Medium Voltage
MW	Mega Watts
NIST	National Institute of Standards and Technology
PHEVs	Plug-in Hybrid Electric Vehicles
PMU	Phasor Measurement Unit
PNNL	Pacific Northwest National Laboratory
PQ	Power Quality
PV	Photovoltaic
R&D	Research and development
RD&D	Research, Development and Demonstration
RES	Renewable Energy Sources
RF	Radio Frequency
SA	Substation Automation
SCADA	Supervisory Control And Data Acquisition
SEESGEN-ICT	Supporting Energy Efficiency in Smart GENeration grids through ICT
SGCC	State Grid Corporation of China
T&D	Transmission and Distribution
ToU	Time of Use
TSO	Transmission System Operator
TVPP	Technical Virtual Power Plant
TWh	Trillion Watt-hours
UHV	Ultra High Voltage
US	United States (of America)
VPP	Virtual Power Plant
WAMS	Wide Area Monitoring System
WiMax	Worldwide Interoperability for Microwave Access

1. Introduction

In most of the countries, the electrical and distribution systems were constructed when energy production was relatively cheap. The important aspect of the grid reliability was based on having excess capacity in the system, with unidirectional electricity flow to consumers from centrally dispatched power plants. Investments in the electric system were made to meet increasing demand and not to change fundamentally the way the system works.

While innovation and technology have dramatically transformed other industrial sectors, the electric system has continued to operate in the same way for decades. The lack of investment, combined with an asset life of 40 years or more, has resulted in an inefficient and increasingly unstable electric system [1]. Climate change, rising fuel costs, outdated grid infrastructure and new power-generation technologies have changed the mindset of all stakeholders. It has been revealed that electric power causes approximately 25% of global greenhouse gas missions and utilities are rethinking what the electricity system of the future should look like. It is hoped that renewable and distributed power generation will play a significant role in reducing greenhouse gas emissions. Demand side management (DSM) seems promising to improve energy efficiency and reduce overall electricity consumption. The real-time monitoring of grid performance will improve grid reliability and utilisation, reduce blackouts and increase financial returns on investments in the grid. These changes on the demand and supply side may require a new, more intelligent smart grid system that can manage the increasingly complex electric grid efficiently.

Taking into account above mentioned challenges, the energy community starting to integrate information and communications technology (ICT) with electricity infrastructure. Technology enables the electric system to become ”smart.” The real-time information allows utilities to manage the entire electricity system as an integrated framework, actively sensing and responding to changes in power demand, supply, costs, quality and emissions across various locations and devices. Similarly, better information enables consumers to manage energy use to meet their needs. These changes on both the demand and supply side require a new, more intelligent smart grid system that can manage the increasingly complex electric grid.

The systematic development of electric power networks to include better communications and make use of modern computer technology will provide more intelligent automation devices and better optimised systems than ever. It will enable utilities to meet regulatory requirements and customer demands for reliable power flow from both conventional and renewable energy sources (RES) [2]. Efficient development and management of such smart grids is considered an important research topic for the next years in both academia and industry. The creation of a smart grid allows the addition of various kinds of information technology (IT), such as sensors, digital meters and a communications networks to the internet or to the dumb wires. A smart grid would be able to avoid outages, save energy and help other green undertakings, such as electric cars and distributed generation (DG).

The vision of smart grid gathers the latest technologies to ensure success, while keeping the high flexibility to adapt to further developments. Network technologies will improve the efficiency of supply by increasing power transfers and reducing energy losses, while power electronic technologies will improve the quality of electric supply. Advances and developments in simulation tools will greatly assist the transfer of innovative technologies to practical application for the benefit of both customers and utilities. 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 efficiency. Key elements of the smart grid vision include:

- Creating a toolbox of proven technical solutions that can be deployed rapidly and cost effectively, enabling existing grids to accept power injections from all energy resources.
- Harmonising regulatory and commercial frameworks to facilitate cross-border trading of both power and grid services, ensuring that they will accommodate a wide range of operating situations.
- Establishing shared technical standards and protocols that will ensure open access, enabling the deployment of equipment from any chosen manufacturer.
- Developing information, computing and telecommunication systems that enable businesses to utilise innovative service arrangements to improve their efficiency and enhance their services to customers.
- Ensuring the successful interfacing of new and old designs of grid equipment to ensure interoperability of automation and control arrangements.

Future electricity grids are smarter in several ways. Firstly, customers are allowed to take an active part in the supply of electricity. DSM becomes a source of generation and savings are rewarded. Secondly, the new system offers greater efficiency as links are set up across Europe and beyond to draw on available resources and enable an efficient exchange of energy. In addition, environmental concerns will be addressed, thanks to the exploitation of sustainable energy sources. The potential benefits are impressive, but the big challenge is that how they will be achieved. The smart grid should have the following characteristics [3]:

- Adaptive, with less reliance on operators, particularly in responding rapidly to changing conditions
- Predictive, in terms of applying operational data to equipment maintenance practices and even identifying potential outages before they occur
- Integrated, in terms of real-time communications and control functions
- Interactive between customers and markets
- Optimised to maximise reliability, availability, efficiency and economic performance
- Flexible, by fulfilling customers' needs while responding to the changes and challenges ahead
- Accessible, by granting connection access to all network users, particularly for renewable power sources and high efficiency local generation with zero or low carbon emissions
- Reliable, by assuring and improving security and quality of supply, consistent with the demands of the digital age with resilience to hazards and uncertainties
- Economic, by providing best value through innovation, efficient energy management, competition and regulation
- Secure from attack and naturally occurring disruptions.

There is a great deal of variation both within the power industry and academia to what exactly should be included under the umbrella of a smart grid, it is not only the concept of developing smart meters or home automation, rather there is much more to consider. For instance, according to [4], [5], [6], the smart grid refers to a way of operating the power system using communication technology, power electronic technologies and storage technologies to balance production and consumption at all levels, i.e. from inside of the customer premises all the way up to the highest voltage levels.

Smart grid might be defined by its capabilities and operational characteristics rather than by the use of any particular technology. Deployment of smart grid technologies will occur over a long period of time, adding successive layers of functionality and capability onto existing equipment and systems. Technology is the key consideration to build smart grids and it can be defined by broader characteristics [3].

2. Motivation to build future smart grids

Recently, energy saving and energy security have become major issues. We are facing energy deficiency in some countries which not only impacts economics, society and development of the country, but also results in the global warming. A set of recent developments are about to change this picture and put the electricity networks under pressure to change. The drivers for change are both external to the network, like preparing for a low-carbon future by reducing greenhouse gas, as well as internal, like the need for replacement of an ageing infrastructure. One of the main external drivers is the European Union (EU) Energy and Climate Package, which has set out ambitions targets for year 2020 and beyond as [7]:

- 20% reduction of greenhouse gas emissions (compared to 1990 levels)
- 20% of RES in the EU 27 energy mix (today 6.5%)
- 20% reduction in the primary energy used (saving 13% compared to 2006 levels).

The EU's triple commitment to reduce CO_2 emissions by 20%, sourcing 20% of its total energy (transport, heating, lighting and electricity) from renewable sources and improving energy efficiency by 20%, all by year 2020, represent a considerable challenge for today´s energy sector. For the electricity grid, the triple commitment is even more challenging as it means that approximately 35% of all electricity will be generated from renewable sources. In addition, more electricity applications will appear in the future, such as the electrical vehicles and heat pumps coming into use today. This will have a considerable impact on the electricity grid. Generation of electrical energy, however, is currently the largest single source of carbon dioxide emissions, making a significant contribution to climate change. To mitigate the consequences of climate change, the current electrical system may needs to undergo significant adjustments in compliance with the three pillars of the EU energy policy (i.e., security of supply, sustainability and market efficiency) [7].

Traditional solutions can be considered to resolve issues posed by the new challenges, e.g., building new lines and substations to integrate more renewable generation whereas the smart grids approach would involve the development of more ICT solutions in the network to allow a higher penetration of renewables connected to existing lines and substations. In this case the traditional approach would give a solution, but it would be much more expensive and might not be feasible because it offers great resistance to build new infrastructure. This does not mean that more traditional infrastructure is not needed even with the "smart grids" approach, but it means that the smart grids approach is looking for the most efficient way to meet the new challenges and will be less expensive in the long run. As a matter of fact, three major components of the smart grids are distributed intelligence, communication technologies and automated control systems.

There is considerable security risk in the design of the grid with centralised generation plants serving remotely located loads over long transmission networks. To enhance the security of energy in the country, the promotion of use of RES is an important strategy. Photovoltaic (PV) and wind power have been receiving special attention because they are environmentally friendly and they do not emit greenhouse gas. This results in the high penetration of such RES into electric power systems in the future. However, adding more DG, in particular variable sources like wind and solar, face new operational challenges. Nevertheless, the power generations from wind and solar are intermittent and depend on the weather condition. These power fluctuations directly affect not only power quality (PQ) such as system frequency and voltage, but also system stability and security. The increased share of DG has been achieved with the "fit and forget approach", focusing on connection rather than integration. In practice, these energy sources have been connected to the power system under limits established by planning studies assuming worse case conditions, limiting their functionality and applying strict relay settings designed for early unit tripping. With the current integration approach only energy is displaced but not capacity because the lack of control mechanisms restrain any sort of management and conventional units are still required to provide system services. Therefore, the overall objective of maintaining and even reinforcing electric power security has to be accomplished in an economic optimal way integrating conventional and non-conventional power plants controllable and non-controllable into the power system operation. To control the power systems under above situation, the smart grid have been proposed by integrating ICT, RES, control and instrumentation.

The changes in the way electricity is purchased and sold at the wholesale level have drastically increased the amount of power being traded between regions. Even the way we use electricity has changed in many ways. In our existing digital society, PQ is of much greater importance than it was just 15 years ago, both for end consumers and businesses like chip manufacturing, where even small disturbances in the power supply can have detrimental effects to production. Our society is critically dependent on a reliable supply of electric power. The ageing infrastructure of our transmission and distribution (T&D) networks threatens the reliability and quality of supply. Now a days, the distribution system operators (DSOs) have also strict requirements and objectives to keep the reliability of the network high (e.g. reducing number of interruptions and their duration) and delivering better quality of power to the end customers. Significant improvements in the reliability of power supply can be achieved through improved monitoring, automation and information management.

The efficiency of the power grid itself has come under consideration. The existing electric grid is not performing at the same level as it was decades ago. Energy losses in the T&D system have nearly become doubled from 5 to 9.5% in 1970 to 2001. Generally speaking, up to 8% of the electric energy leaving a power plant is lost in the T&D network in most of the advanced power systems. Reliability that has been the major concern of utilities and grid operators is now only one of a wide range of considerations in power system planning, operation and management. Energy efficiency has now come to the force as another key issue that, in many cases (notably in areas suffering from transmission congestion), is closely linked with reliability.

Considering energy demand side, the consumers are interested to get ever greater control over their energy usage and the application of technology is already meeting this requirement. Smart metering, e.g., allow utility customers to take advantage of time-of-use (ToU) pricing that was formerly available only to large commercial/industrial users. Self-generation (e.g., solar panels) is also on the rise and is driving a need for net metering to manage power sales from many small-scale generators.

Regulators have taken into account considerations of all these trends. Many examples of the regulatory support for expanding renewable generation, enhancing grid efficiency and system reliability can be seen. These efforts range from local government actions to ease the installation of solar panels to state/provincial requirements for renewable generation, national reliability standards and cross-border agreements for improved interconnection between power systems.

Taking all of these factors into consideration, it becomes apparent that the grid we know today is insufficient to serve us in the future, means we may need an innovative grid to meet the requirements and challenges of the future energy infrastructure [3].

3. Initiatives taken by EU and IEA to promote smart grid technology

The vital links between electricity producers and consumers have been provided with great success by Europe's electricity networks since many decades. The basic architecture of these networks has been developed to meet the needs of large, predominantly carbon-based generation technologies, located remotely from demand centres. The energy challenges that Europe is now facing are changing the electricity generation landscape. The drive for lower-carbon generation technologies, combined with greatly improved efficiency on the demand side, will enable customers to become much more interactive with the networks. More customer-centric networks are the way ahead, but these fundamental changes will impact significantly on network design and control. In this context, following initiatives have been taken by EU and International Energy Agency (IEA) to cope with the challenges associated with future energy demands.

3.1 European technology platform (ETP)

The ETP SmartGrids was established in the year 2005 to create a joint vision for the European networks of the year 2020 and beyond. The platform consists of representatives from industry, T&D system operators, research bodies and regulators. It has identified clear objectives and proposes an ambitious strategy to make a reality of this vision for the benefits of Europe and its electricity customers. The preliminary definition of smart grid according to ETP is gven as, "A smart grid is an electricity network that can intelligently integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to efficiently ensure sustainable, economic and secure electricity supply" [8].

The new electricity networks concept across Europe has been developed by SmartGrids. The initiative responds to the growing challenges and opportunities, bringing benefits to all users, stakeholders and companies that perform efficiently and effectively. SmartGrids mission is to create a shared vision which enables Europe's electricity grids to meet the challenges and opportunities of the 21st century; to fulfil the expectations of society; and to strengthen the European business context for the electricity sector and its international opportunities. SmartGrids is a necessary response to the environmental, social and political demands placed on energy supply. SmartGrids will use revolutionary new technologies, products and services to create a strongly user-centric approach for all customers. The SmartGrids vision is about a bold programme of research, development and demonstration that charts a course towards an electricity supply network that meets the needs of Europe's future [8].

A technology-enabled electric system will be more efficient, enable applications that can reduce greenhouse gas emissions and improve power reliability. Specifically, a smart grid can:

- Reduce peaks in power usage by automatically turning down selected appliances in homes, offices and factories
- Reduce waste by providing instant feedback on how much energy we are consuming
- Encourage manufacturers to produce "smart" appliances to reduce energy use
- Sense and prevent power blackouts by isolating disturbances in the grid.

A proportion of the electricity generated by large conventional plants will be displaced by DG, RES, demand response (DR), DSM and energy storage. The operation of system will be shared between central and distributed generators. Control of distributed generators could be aggregated to form virtual power plants (VPPs) to facilitate their integration both in the physical system and in the market. Additional standby capacity might be required, which could be called upon whenever the intermittent RES ceases to generate power as shown in Figure 1.

Seeking at European level rather on national one to balance power might be economically efficient. The huge amount of fast-controllable hydro power in the Nordic and other mountainous countries of Europe could be used as real-time balancing power for those areas in central Europe, where a large part of electricity generation could be provided by non-controllable primary energy. It is not possible to carry out efficient integration of DG without changes to T&D network structure, planning and operating procedures. As a matter of fact, it has been envisaged that there will be less of a distinction between these network types, as medium voltage (MV) distribution networks become more active and share many of the responsibilities of transmission.

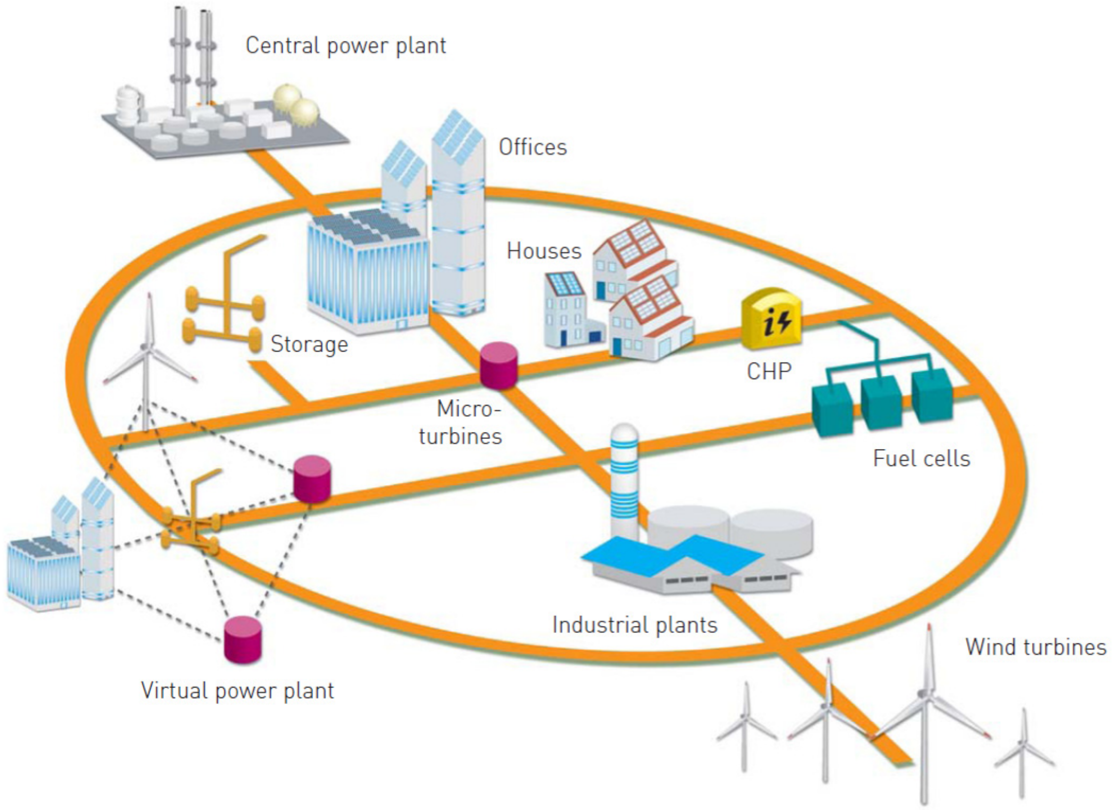

Figure 1. Future power network from the perspective of ETP. [8]

The electricity markets liberalisation is an important factor to take into account in the future markets. It affects on the business framework of companies in a fundamental way. By implementing it well, the benefits of competition, choice and incentives for an efficient development can be brought. The change might be better described as a revision of the traditional monopoly-based regulation of electricity supply. It has been accompanied by a trend towards an open market in power, meaning free choice of power supplier by electricity consumers. In addition, liberalisation has separated the responsibility for the secure T&D operation from the electricity generation business. The whole electricity sector business is in a fundamentally changed commercial, regulatory and environmental context. The role of aggregator is the central one in making trade exchanges between different energy players as shown in Figure 2.

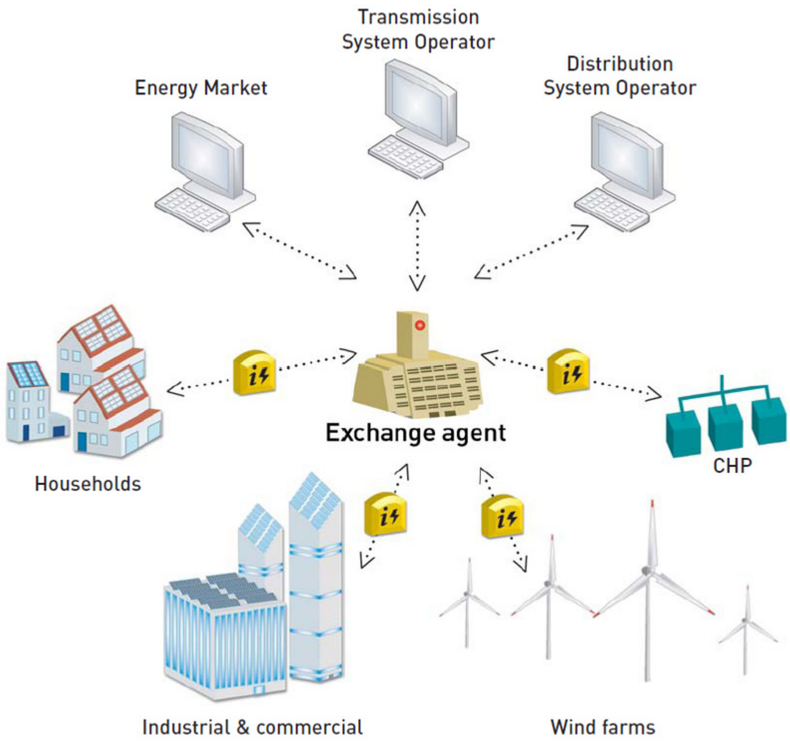

Figure 2. The role of aggregator in new energy business model.

3.2 IEA DSM Task XVII

IEA has several implementing agreements dealing with DG such as wind, PV, combined heat and power (CHP), energy storage and DSM. However, the question of how to handle the integration of various distributed energy resources (DER) is not actually studied.

The main objective of IEA DSM Task XVII is the integration of DSM, DG, RES, energy storages and investigating how to achieve a better integration of flexible demand with DG, energy storages and smart grids. This would lead to an increase of the value of DR, DSM, DG and a decrease of problems caused by intermittent DG (mainly based on RES) in the physical electricity systems and at the electricity market [9].

Renewable sources are producing large amounts of variable generation which are not fully forecastable and it may cause increasing problems in electrical networks (both in local distribution and transmission networks). We can already observe at some places an increase in the network stresses and the needs for upgradation to provide extended capacity and flexibility to integrate the variable generation. It also increases the need for flexible, dispatchable, fast-ramping generation for balancing variations in load, intermittent resources and contingencies such as the loss of transmission or generation assets.

Similar problems can be seen at market: national and local balances between supply and demand are more complicated to manage with high levels of variable generation, which can increase total financial electricity costs. There are two tasks for integrating variable generation and DER, both locally and globally: integrating them into the electricity network and into the energy market.

One solution to decrease the problems caused by the variable output of some DG is to add energy storages into the systems (centralised or distributed energy storages). Another way is to use flexibility in electricity consumption, e.g. using DR. In this sense DG, distributed energy storages and DR can be seen as an integrated DER. Combining the different characteristics of these resources is essential in increasing the value of DG in the energy market.

The idea behind this programme, as well as behind several other programmes around the world, is that better coordination between local energy sources, controllable loads, storage possibilities which can reduce significantly the costs of integrating renewable sources into the networks.

The vision for the integration of DER is a smart grid platform that would link a web of diverse generation sources, including a variety of fossil fuels and renewable and distributed sources, across the grid to a large set of consumers with possibilities for improved energy efficiency, local generation, controllable loads or storage devices. The grid, along with analytics, communication technologies and distributed intelligence, is used to coordinate and balance sources, storage and loads to produce a reliable power system for more moderate costs than a traditional and centralised approach. It is expected that the costs of a system with a better DER integration would be reduced compared to the present situation, because of the inclusion of more energy efficiency and renewables, but also of a lesser use of expensive peaking power and a better use of the T&D assets. This vision for the future grid can lead to a lower adverse environmental impact. In the future system, a proportion of the electricity generated by large conventional plants will be displaced by DG, RES, DR, DSM and energy storage. Additional standby capacity might be required, which could be called upon whenever the variable output type of RES ceases to generate power and there is not enough DR or energy from storages.

Several models for the future electricity system recognise the fundamental fact that with increased levels of DG and active demand-side penetration, the distribution network can no longer act as a passive appendage to the transmission network. The entire system has to be designed and operated as an integrated unit. In addition, this more complex operation must be undertaken by a system where ownership, decision-making and operation are also dispersed. Three conceptual models can be mentioned as microgrids, active networks supported by ICT and an internet model; all of which could find applications, depending on geographical constraints and market evolution.

Microgrids are generally defined as low voltage (LV) networks with DG sources, together with local storage devices and controllable loads (e.g. water heaters and air conditioning). They can have a total installed capacity in the range of a few hundred kW to a couple of MW. Although microgrids operate mostly connected to the distribution network, they can be automatically transferred to isolated mode in case of faults in the upstream network and then resynchronised after restoration of the upstream network voltage. Within the main grid, a microgrid can be regarded as a controlled entity capable of operating as a single aggregated load or generator and, given attractive remuneration, as a small source of power or as an ancillary service supporting the network.

Active networks are a possible evolution of the current passive distribution networks and may be technically and economically the best way to initially facilitate DG in a deregulated market. Active networks have been specifically conjectured as facilitators for increased penetration of DG and demand-side resources, building on new ICT technology and strategies to actively manage the network.

The internet model effectively takes the active network to the global scale but distributes control around the system. The flow of information around the internet uses the concept of distributed control where each node, web host computer, email server or router, acts autonomously under a global protocol. In the analogous electricity system every supply point, consumer and switching facility corresponds to a node. The internet-type systems also enable new types of concepts in the electricity market, such as VPPs or virtual utilities. A conventional power plant generates electricity in one location, generally using one type of generating technology and is owned by one legal entity. A VPP is a multi-fuel, multi-location and multi-owned power station.

Based on the characteristics of smart grids, it is possible to reach energy infrastructures and systems having a lower total capacity and emissions compared with the structures based on the existing technology and systems (see Figure 3). “Fit and forget” approach means that networks and central generation are build on the basis of present technologies where centralised control is applied to central generation and transmission and passive control to distribution systems. The ”Integrated DG & DSM/DR” approach is based on distributed control and efficient integration of DER. This means that the same demand needs less generation and network capacity than the “fit and forget” alternative.

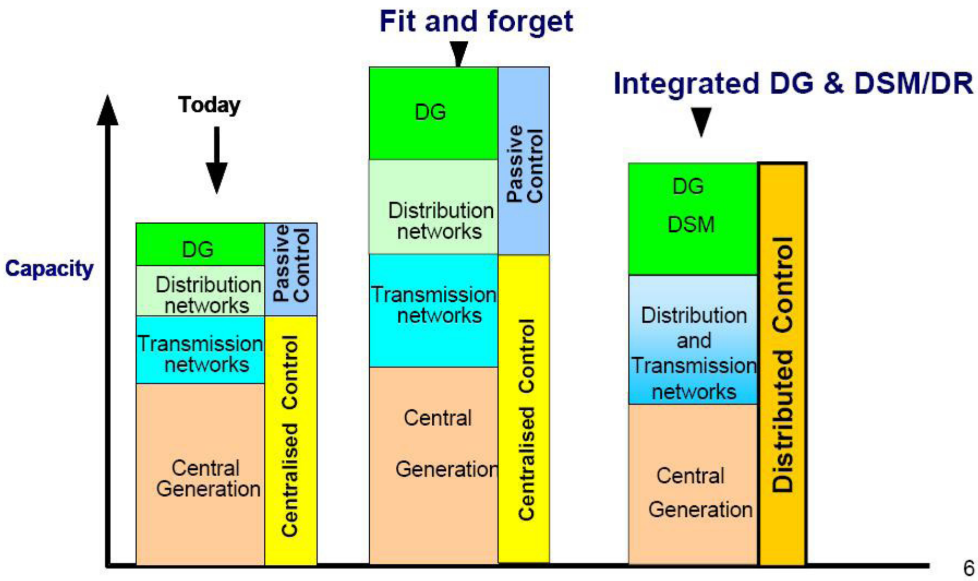

Figure 3. Impact of a smart grid on the need for energy system capacity. Two basic alternatives for the future electric systems: "Fit and forget" and "Integrated DG&DSM/DR".

3.3 European electricity grid initiative (EEGI)

The EEGI proposes a nine year European research, development and demonstration (RD&D) programme initiated by electricity T&D network operators to accelerate innovation and the development of the electricity networks of the future in Europe, a so-called smart grid. The smart grid will be a user-centred, market-based, interactive, reliable, flexible and sustainable electrical network system. Its deployment will start progressively over the period from years 2010–2030 and result in benefits such as [10]:

- Increased hosting capacity for renewable and distributed sources of electricity
- The integration of national networks into a market-based, truly pan-European network
- A high level of quality of electricity supply to all customers
- The active participation of users in markets and energy efficiency
- The anticipation of new developments such as a progressive electrification of transport
- An economically efficient deployment of future networks, for the benefit of grid users
- The opening of business opportunities and markets for new players in the smart grids arena.

A European-level planning and implementation of the EEGI RD&D programme is necessary to avoid unnecessary duplication of efforts, promote the replication of new developments and the exchange of best practices. In case of European transmission networks and markets, it is crucial to ensure appropriate cross-border coordination of planning and operations. The Initiative will also promote solutions that support European standardisation and interoperability. The proposed RD&D programme focuses on system innovation rather than on technology innovation, addresses the challenge of integrating new technologies under real life working conditions and validating the results. The network operators are responsible for the secure operation of the electricity system: they need therefore to lead the tests of new solutions through large scale demonstration projects. The demonstrations of new developments will allow evaluating their benefits, estimating their costs and preparing scaling up and replication for an accelerated take-up by all network operators.

The demonstrations also require the involvement of research players and market participants such as generators, users, retailers, T&D manufacturers, ICT providers and smart meter manufacturers. These stakeholders have been consulted in the preparation of the programme and are expected to play an important role in the implementation of the projects.

The operation of electricity networks is regulated and remunerated, with tariffs defined by regulatory authorities. In most cases, current tariff schemes do not provide sufficient incentives to support large scale RD&D projects. This situation is expected to evolve in the future as the Third Internal Energy Market package foresees that tariffs incentives should support a number of research activities. Regulators are expected to have an important role in the development and implementation of the programme and have been closely consulted in its preparation.

Since several definitions already exist, the focus of the EEGI has been on defining the major smart grids functionalities necessary to reach the vision and the goals of the program rather than on the definition. To meet this goal, a smart grid model has been developed to guide in the process of defining the functionalities and the needed projects, to ensure that all critical issues are covered and avoiding overlaps. The Figure 4 summarises the model.

- Level 0 covers centralised electricity generation technologies, the majority being connected to the European Transmission Grid and located anywhere in Europe or beyond, including present and future wind or solar farms
- Level 1 covers transmission issues, the responsibility of European TSOs
- Level 2 covers the issues that are the exclusive responsibilities of the DSOs

- Level 3 to 5 cover issues that require the involvement of DSOs, grid users connected to the distribution network (as generators and customers) and free market players (as retailers and aggregators).

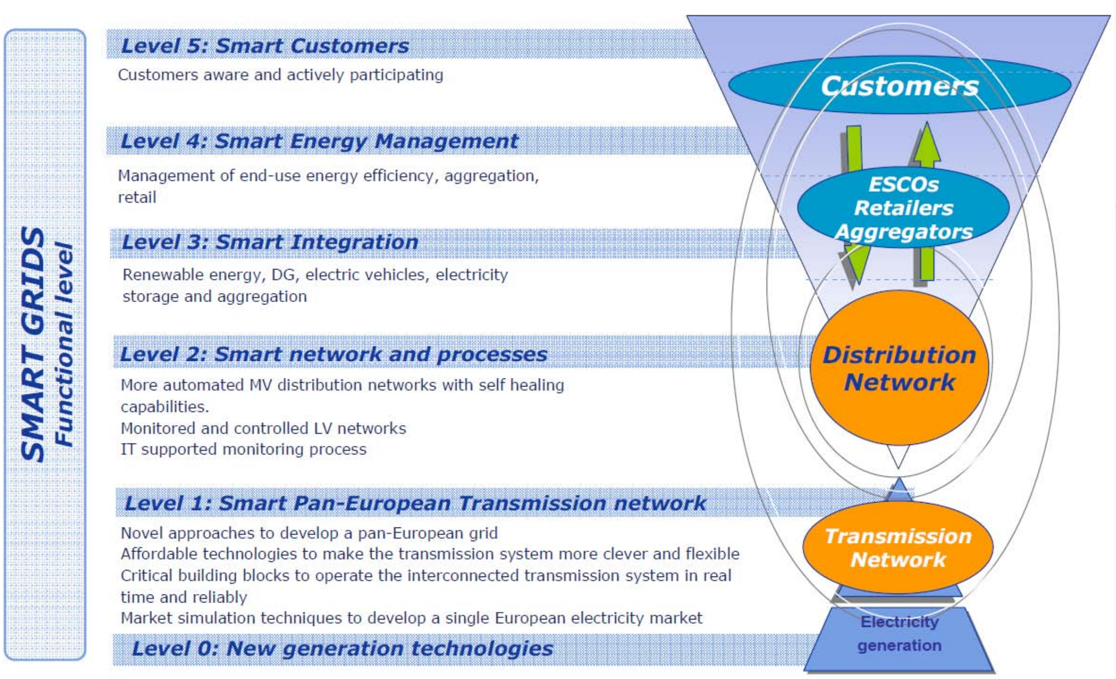

Figure 4. The different functional levels of the smart grid defined by EEGI.

3.4 European energy research alliance (EERA)

The objective of EERA joint programme on smart grids is to lower investments in electricity grid by introducing intermittent resources (wind, PV), load management by electric vehicles (EVs), grid stability and power management. The balance between demand and supply will be obtained by considering market share production options (PV, micro-CHP, wind) and market share demand options (electric heat pumps, intelligent appliances and EVs). Smart grids are also required because the capacity of electricity grid varies throughout Europe as well as there are major differences between countries energy markets [11].

EERA programme will also investigate the consequences of DG, new types of electric appliances and higher network loads on the grid stability and PQ such as:

- Increasing voltage fluctuations (dips and spikes)
- Local reactive power shortage
- Frequency instability (less synchronous rotating mass)
- Grid pollution (harmonics).

The main activities within this programme include network operation, developing and choosing effective new control structures, grid integration of new control structures, emergency situations and microgrids, energy management, simulation, analysis of market design, information and control system interoperability, comparison on system interoperability, define guidelines on technical communications, electrical storage technologies, integration and control of electrical storage systems and economic and technical benefits for implementing this technology.

4. Smart grid concepts and architectures developed on projects basis worldwide

Many smart grid concepts and architectures have been developed based on the projects initiated in Europe and United States (US). The descriptions of some of the major concepts are given as:

4.1 Development of virtual power plant (VPP)

In practice, current policy of connecting DER units is generally based on a so-called ‘fit and forget’ approach. With large-scale deployment we are now entering an era where this approach is beginning to adversely impact the deployment rates of DER/RES and increasing the costs of investment and operation of the electric power system as well as having impact on the integrity and security of the system [12].

In order to address these problems, DER units must take over the responsibilities from large conventional power plants and provide the flexibility and controllability necessary to support secure system operation. With integration of DER units, DSOs also need to operate their network actively using local resources. This represents a shift from traditional central control philosophy, presently used towards control typically hundreds of generators to a new distributed control paradigm applicable for the operation of millions of generators and controllable loads. DER units are too small and too numerous to be visible or manageable on an individual basis. The concept of VPP counteracts this problem by aggregating DER units into a portfolio that has similar characteristics to transmission connected generation today (see Figure 5).

In late 2005, a consortium of 20 different partners from research and industry launched the four-year FENIX (Flexible Electricity Network to Integrate the eXpected energy evolution) research project. The objective of FENIX was to conceptualise, design and demonstrate a technical architecture and commercial and regulatory framework that would enable DER units to become the solution for the future: a cost-efficient, secure and sustainable EU electricity supply system. To facilitate this solution, the VPP concept was further developed and tested in FENIX. The VPP enables large-scale technical and commercial aggregation of DER units and thereby providing services to system operators and energy market actors.

The VPP is a core FENIX concept which enables the integration of DER into power system operation. Through this concept individual DERs can gain access and visibility across energy markets, benefit from VPP market intelligence to optimise their position and maximise revenue opportunities. Furthermore, system operation can benefit from optimal use of all available capacity connected to the grid, as well as increased efficiency of operation. The VPP makes distributed resources visible to the system operator and presents a resource that can be used for active control of electricity networks.

A VPP aggregates the capacity of many diverse DERs. It creates a single operating profile from a composite of the parameters characterising each DER and can incorporate the impact of the network on their aggregate output. In other words, VPP is a flexible representation of a portfolio of DER that can be used to make contracts in the wholesale market and to offer services to system operators. Because of their size and multitude, distributed generators and responsive loads are currently not fully integrated into system operation and market-related activities. The VPP concept counteracts this problem by aggregating individual characteristics from a portfolio of DERs, so that it can be used in a manner similar to transmission-connected generation. As any large-scale generator, the VPP can be used to facilitate DER trading in various energy markets and can provide services to support T&D system management. In the FENIX project, these activities of market participation and system management and support are described respectively as "commercial" and "technical" activities, corresponding to the concepts of commercial VPP (CVPP) and technical VPP (TVPP).

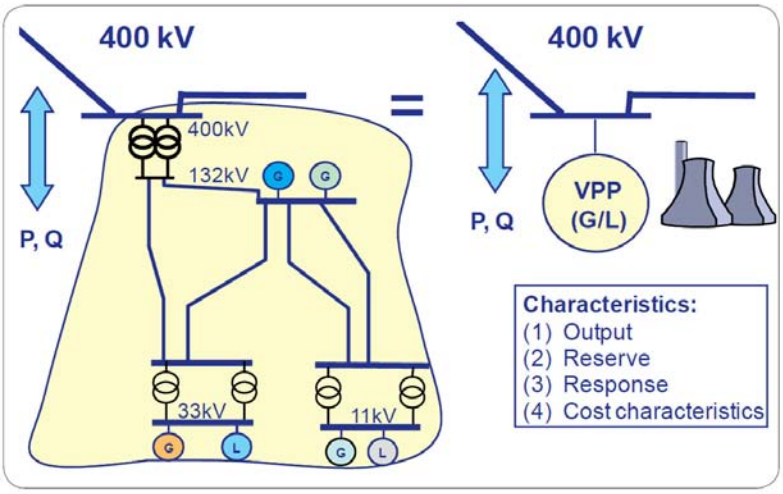

Figure 5. Characterisation of DER as a VPP. [12]

CVPP is characterised by an aggregated profile and output which represents the cost and operating characteristics of the DER portfolio. The impact of the distribution network is not considered in the aggregated CVPP profile. CVPP functionality includes trading in the wholesale energy market, balancing of trading portfolios and provision of services that are not location-specific to the system operator. The operator of a CVPP can be any third party or balancing responsible party with market access, such as an energy supplier. The CVPP can be composed of any number of DER and one distribution network area may contain multiple aggregated portfolios. DER owners are free to choose a CVPP to represent them in the wholesale market and towards the TVPP.

TVPP consists of distributed resources from the same geographic location. It is represented through an aggregated profile which includes the influence of the local network on the portfolio output and also represents the DER cost and operating characteristics. TVPP functionality includes local system management for DSOs, as well as providing system balancing and ancillary services to TSOs. The operator of a TVPP requires detailed information on the local network, so typically this will be the DSO. TVPP provides the system operator with visibility of energy resources connected to distribution network, allowing DG and demand to contribute to transmission system management.

The core aspects of FENIX include three interdependent subjects of research whose outcome forms the basis for the operation of future highly decentralised electricity supply systems. These include; the distributed system control architecture, the information and communication architecture and the supporting market and commercial structure. Figure 6 represents the general FENIX architecture diagram. This architecture could be applied anywhere in Europe. It was designed such it could:

- Embrace peculiarities of any European country
- Optimise the changes in the business of the energy supplier and distribution operator by introducing the new VPP functionalities.

This general FENIX architecture introduces three new elements:

- The FENIX box (FB) interfaces DER local system enabling remote access for monitoring and control
- The CVPP is in charge of the scheduling and energy optimisation functions for DER units
- The TVPP application, at the distribution management system (DMS) performs some type of function, for instance: validates the generation schedules, dispatches DER to address voltage and/or current constraints, etc.

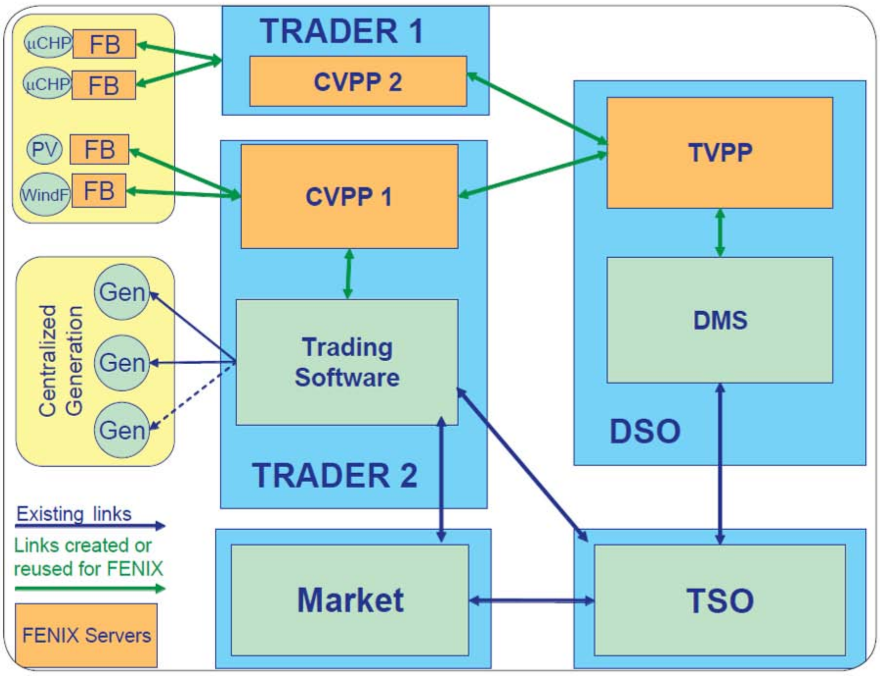

Figure 6. General FENIX architecture. [12]

4.2 Development of active demand (AD) in consumer networks

The existing transmission networks are active and distribution networks are behaving passively. The development of active networks by introducing active demand in consumer networks is a new concept of future smart grid. The recent project ADDRESS (Active Distribution network with full integration of Demand and distributed energy RESourceS) is an example of this concept.

The ADDRESS European project aims to deliver a comprehensive commercial and technical framework for the development of AD in the smart grids of the future. Specifically, ADDRESS is investigating how to effectively develop the participation of domestic and small commercial consumers in the power system markets and in the provision of services to the different power system participants.

In ADDRESS, AD means the active participation of domestic and small commercial consumers in the power system markets and in the provision of services to the different power system participants. Within ADDRESS, "Active Demand" involves all types of equipment that may be installed at the consumers (or prosumers) premises: electrical appliances ("pure" loads), DG (such as PV arrays or micro turbines) and thermal or electrical energy storage systems. [13]. A simplified representation of the proposed architecture is shown in Figure 7. In this architecture, the aggregators are a central concept. The aggregators are the key mediators between the consumers, the markets and the other power system participants, namely:

- The aggregators collect the requests and signals for AD-based services coming from the markets and the different power system participants
- They gather the "flexibilities" and the contributions provided by consumers to form AD-based services and they offer them to the different power system participants through various markets.

It should be emphasised that the "flexibilities and contributions of consumers are provided in the form of modifications of their consumption profile. Therefore, aggregators form their AD services and offers using consumers' "demand modifications" and not consumers' energy profile (i.e. aggregator sells a deviation from the forecasted level of demand and not a specific level of demand) [14].

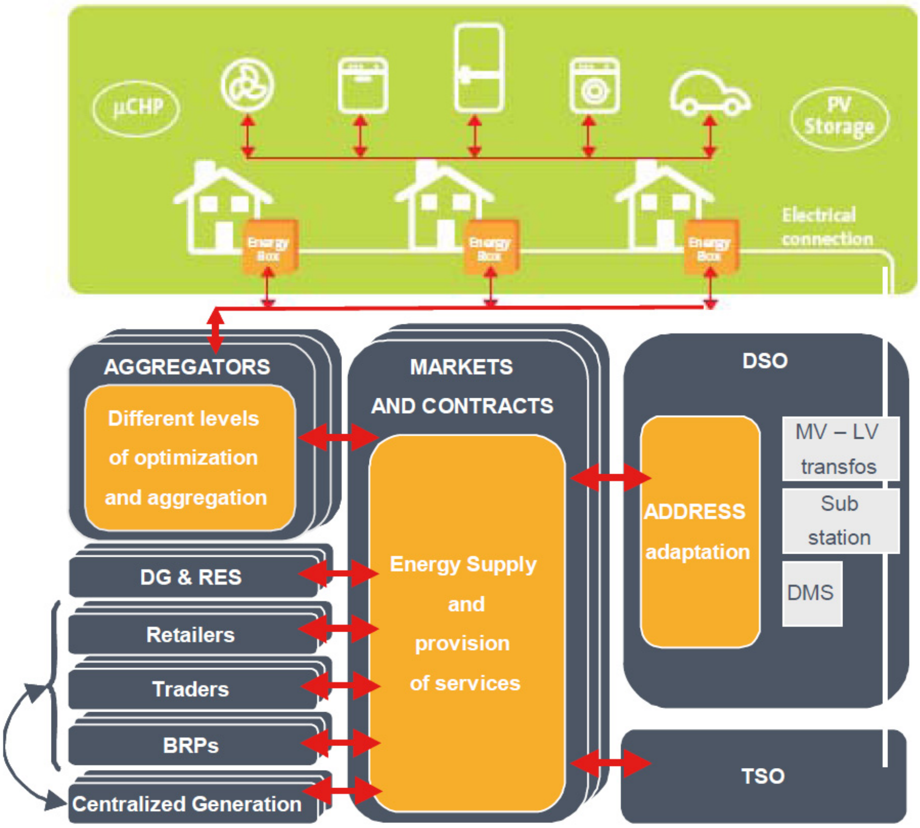

Figure 7. ADDRESS scope and simplified representation of the architecture. [13]

At the consumer level, the energy box (EB) is the interface between the consumer and an aggregator. It is located at the consumer side and it consists of hardware and software (with a certain level of intelligence). It carries out the optimisation and the control of the loads and local DER at the consumer’s premises. It “represents” the consumer from an aggregator’s perspective. It may interact with the meter or the metering system, this might be dependent on local regulatory conditions. If there is no interaction with the metering system, there may well be a parallel installation for determining consumer site production, consumption and possibly PQ [15].

The DSOs also play an important role because AD (as developed in the project) concerns consumers connected to distribution networks. DSOs still continue to ensure secure and efficient network operations. They do so mainly through interactions with the other power system participants and, in particular, with aggregators via markets. Also, they maintain direct interactions with TSOs to ensure secure network operation. The markets consist of all kinds of commercial agreements between power system participants (such as bilateral contracts, forward markets, real-time markets and power exchanges).

Besides aggregation of demand, the following main concepts will be used to achieve the project objectives:

- The basis for the interaction between the power system participants is the exchange of real-time price and volume signals (mainly energy or power-based signals). The real-time scale considered in this project is 15 minutes ahead.
- Local optimisation is needed to determine and meet the requirements for the requested services. Those services may depend on the topology of the concerned network, the geographical location (local/regional) and can vary in time. Therefore, different levels and amounts of distributed intelligence are required. The issue is to put the “right amount” of intelligence in the “right place.”
- A new approach will be used to foster the flexibility and active participation of consumers: the so-called “Demand Approach”. Domestic consumers do not have the same motivations, understanding or technology awareness as producers. Therefore, a different approach has to be taken to enable AD, implying appropriate technological development in the houses, accompanying measures to obtain consumers’ engagement. The services consumers could provide are requested through the price and/or volume signal mechanisms and are provided on a voluntary and/or contractual basis.

ADDRESS will develop technical solutions both at the consumers’ premises and at the power system level to enable active demand and to allow real time consumer response to requests from markets and/or other power system participants. This also implies identifying the possible barriers against active demand deployment and proposing solutions to remove these barriers. In particular, scalable and open communication architecture will make it possible to deal in real time with large numbers of consumers. Equipment considered at the consumer’s premises include: loads (which may or may not be controllable through some external signals), embedded generation, energy storage (thermal, electrical etc.). In addition to technical questions, ADDRESS will also deal with regulatory, economic, societal and cultural aspects which may also be the root causes of possible barriers. This objective implies:

- Identifying the possible benefits of active demand for the power system participants
- Developing the necessary commercial architecture, recommendations for markets and commercial interactions, contractual structures and systems of incentives needed to stimulate the development of active demand and to enable the realisation of these benefits
- Investigating the key factors which influence consumers regarding their decision to "be activated", i.e. to participate in the market in an active manner, e.g. allowing an aggregator to act in an energy market on their behalf.

4.3 Development of DER aggregation business

Aggregation is the process of linking small groups of industrial, commercial or residential customers into a larger power unit to make them visible from the electric system point of view. Aggregation can involve DR and/or DG. Thus, load or generation profiles of individual consumers and/or small generators appear as a single unit to the electric system. Building up a large and flexible portfolio enables aggregators (the entity who aggregates) to operate DER and to provide services to the power system, e.g. system balancing. An aggregator is a facility portfolio manager designing and offering energy-related services to energy consumers, producers and other key players (system operators, electricity traders, etc). Aggregation helps implementing smart grids concepts by reaping some of its benefits to integrate DER units more efficiently. It is by combining these features (more flexibility, lower operating costs) that aggregation will reduce the "gap to profitability" of DER units [16].

A number of technical and non-technical barriers were identified as preventing the rapid deployment of DER across Europe. Market integration, regulation and connection to the grid are amongst the most significant ones. The overarching goal of EU-DEEP (The birth of EUropean Distributed EnErgy Partnership) project was to design, develop and validate an innovative methodology, based on future energy market requirements, and able to produce innovative business solutions for enhanced DER deployment in Europe by the year 2010.

The project objectives were therefore to address the removal of the above barriers by providing solutions based on a demand-pull approach as:

- Innovative business options to favour DER integration
- Equipment and electric system specifications to connect safely more DER units to existing grids
- An in-depth understanding of the effect of large penetration of DER on the performances of the electrical system and on the electricity market
- Market rules recommendations to regulators and policy makers that will support the three studied aggregation routes
- A comprehensive set of dissemination actions targeting all stakeholders of DER in Europe.

EU-DEEP investigated three business models to exploit different types of value possibly unveiled when aggregating DG and/or individual loads within the given energy and regulation context. The three business ideas investigated are:

- **Business model I**: Aggregating commercial and industrial DR to balance intermittent generation
- **Business model II**: Integrating residential scale flexible Micro-CHP into electricity markets
- **Business model III**: Leveraging on the flexibility of aggregated CHP units and DR to extend the conventional energy service company (ESCO) business.

The knowledge gained when exploring the value of aggregation within this business background constitutes the three pillars of the EU-DEEP knowledge building (shown in Figure 8). Each of these pillars required some common background knowledge that is consistent and robust enough to support the complete development of a business case. This background knowledge relates to the technical integration of DER into the power system, to the different sources of value that DER can bring and to the aggregation concept. This knowledge is seen as the foundation on which the three pillar-business models can be built. Finally, the experience gained from the integrating work performed to build the pillars-business models can nourish recommendations for improved framework conditions to expand on the exiting business options. Three recommendations can be used to design business models more safely, thus involving “new pillars” for the knowledge building, i.e. new business models that value DER the most favourably. These recommendations for framework conditions are called the roofing. These three comments fulfil three steps towards the expansion of DER:

- Create the necessary conditions for sustainable DER expansion (foundation)
- Explore DER aggregation business (pillars)
- Propose recommendations to further expand business activities (roofing).

The considered DER technologies in above business models are intermittent RES, CHP and flexible demand. The considered market segments are residential customers (small size), commercial customers (small to medium size) and industrial customers (medium to large). The types of companies investigated to implement DER aggregation are electricity suppliers, energy suppliers (electricity and gas) and ESCO. The summary of three business models is given in Table I.

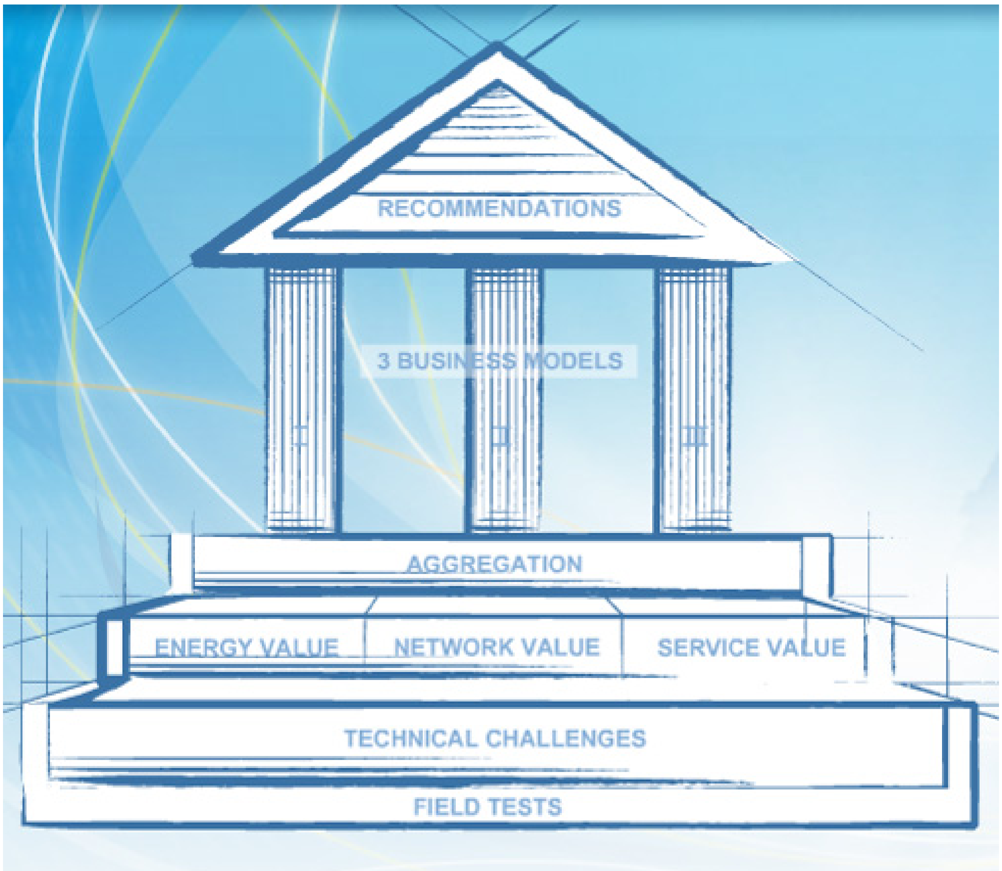

Figure 8. The building structure of EU-DEEP project divided into three major components; roofing, pillars and foundations. [16]

Table 1. Summary of three business models suggested in UE-DEEP project.

Business n°	DER technology	Customers	Company
1	RES + Flexible demand	Medium commercial + Industrial	Electricity supplier
2	CHP	Small residential	Energy suppli-er
3	CHP + Flexible demand	Medium commercial	ESCO

In terms of time horizon and level of risk, business model I could become operational in the short term, business model III is the extension of an existing ESCO business to new emerging services and business model II is a more long term and risky case. This enables studying DER aggregation development both for "today" and "tomorrow". With regards to geographical and regulatory/market contexts, the three business models were analysed in five different countries each: the UK, Germany, Greece, Spain and France.

4.4 Development of active distribution network

The traditional passive network management or "fit and forget" principle in DG connection needs to be changed into active network management (ANM). With proper management of active resources the overall system performance may be improved from presently used practices. DG provides a good potential as a controllable resource for the active network. Other existing controllable resources are direct load control, reactive power compensation and DSM. ANM method adds value by increasing the potential for renewable energy, by improving efficient utilisation of distribution network assets and by supporting distribution network by ancillary services from customer- owned resources [17].

ADINE (Active DIstribution NEtwork) project develops new methods for the electric distribution network management including DER. The new methods for planning and control developed in the project are maximising the use of existing electricity networks and reduces the need for installing new power lines. The project provides better understanding of the potential benefits and problems when different DER units are in active interconnection and participating in the management of the network. To make ANM possible, a set of technical solutions are developed and demonstrated in real-life environment. The ANM method needs technical solutions such as protection, voltage and reactive power control and planning and information systems of networks.

The distribution network management concept of ADINE project is based on existing systems like supervisory control and data acquisition (SCADA), DMS, substation and distribution automation and advanced metering infrastructure (AMI). The ANM system operates on protection, decentralised control and area control levels. The intelligence of ANM is based on investments in controllability and ICT. Area control level may e.g. be used to coordinate individual resources and thereby increase the synergy benefits of network management.

ANM concepts add new features for protection system and automatic control system levels. New protection system features are e.g. distance and differential protection schemes and communication based loss of main's protection. The ANM concept includes at decentralised control system level local voltage, PQ and frequency control, load shedding and production curtailment features. Many new features are also added for the area control level like coordinated voltage control, power flow management, fault location schemes, automatic network restoration and island operation. The aim of ANM is to add more flexibility for network management in order to utilise existing network assets more efficiently. The addition of flexibility comes from the utilisation of active resources through grid code requirements or ancillary services provided by resources. Active resources are needed to integrate as a part of distribution system instead of just connecting. Active resources are typically utilised in extreme network conditions when network is not capable to transfer produced wind power. The overview of the ANM concept in the ADINE project is depicted in Figure 9 where all hardware devices like protection relays, automatic voltage regulator (AVR) of tap changer, AVR of DG units, static synchronous compensator (STATCOM) controller and power factor controller are working in decentralised way. On the top of the decentralised control system there exists also a centralised system for distribution network management.

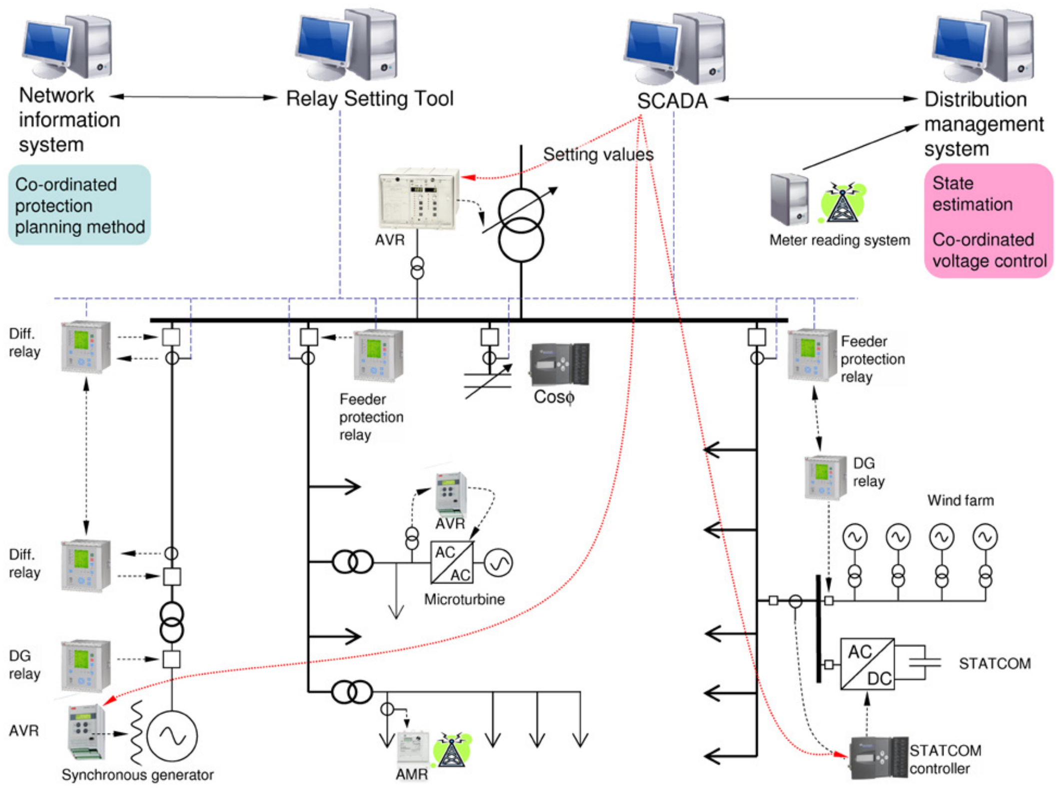

Figure 9. Overview of the ANM concept in the ADINE project. [17]

4.5 ICT applications to develop intelligent grid

Energy efficiency, demand side control and RES are considered as some of the effective solutions to counteract the worldwide climate changes. The reorganisation of the electric distribution network, which has been traditionally planned and operated as a passive system, is fundamental to implement the envisaged solutions. This renovation has already begun and the distribution systems are currently moving towards smart distributed power generation grids. Nevertheless, the operation of smart grids is quite complex and requires novel ICT-based applications for real time process control and communication, adaptive protection, prognosis techniques and portfolio management. Here are few examples of projects where ICT application has played a vital role to make grids smarter and more intelligent than ever before. Following are recent projects where this concept has practically been implemented to build future smart grids.

4.5.1 IntelliGrid program

The IntelliGrid program develops and evaluates technologies and methodologies for implementing a smart power grid infrastructure. The program focus is on the communications and information infrastructure that will become the foundation for many smart grid applications, as well as the implementation of security for this infrastructure. When this enabling infrastructure is matched with smart grid applications in transmission, distribution, or at a customer interface, then the resulting smart grid can reach significant gains in reliability, capacity, DR and it offers value added customer services.

The mission of this program is to accelerate the transformation of the power delivery infrastructure into the intelligent grid needed to support the future needs of society. To achieve benefits identified by stakeholders, the power delivery system of the future will be interactive with consumers and markets, self-healing and adaptive to correct problems before they become emergencies, Optimised to make best use of resources and equipment, predictive rather than reactive to prevent emergencies ahead rather than solve after, accommodates a variety of generation options, Integrated to merge all critical information and more secure. Achieving power delivery system of the future by integrating two infrastructures, i.e., electrical and intelligence infrastructures as shown in Figure 10 [18].

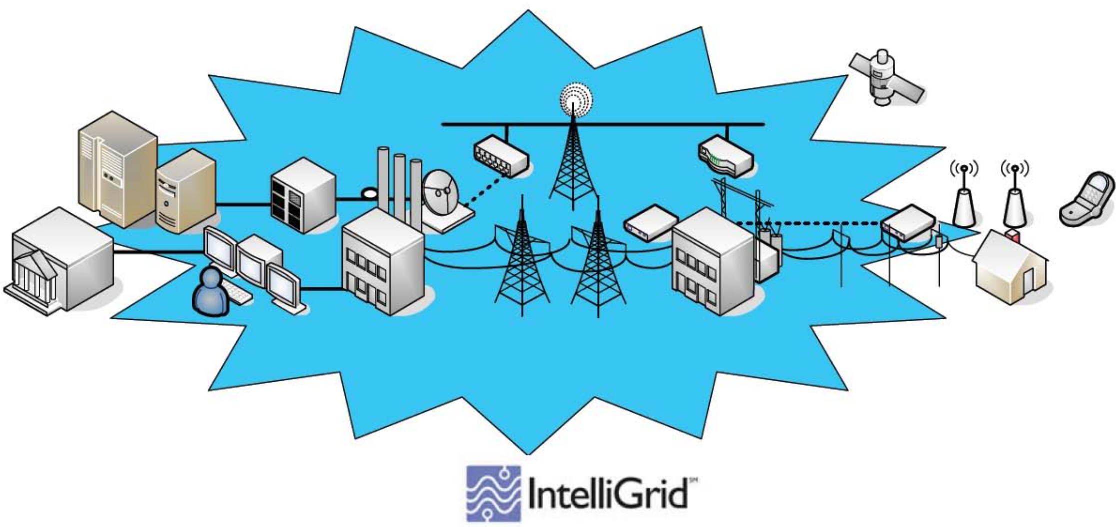

Figure 10. Power delivery system of future by Integrating electrical and intelligence infrastructures.

A major early accomplishment of the electric power research institute (EPRI) research is the IntelliGrid Architecture, an open-standards, requirements-based approach for integrating data networks and equipment that enable interoperability between devices and systems. The goal of the IntelliGrid Architecture project is to assemble an integrated energy and communications system architecture to support a self-healing grid. The IntelliGrid Architecture project lays the foundation for specifying and integrating advanced intelligent equipment across the electric energy industry as well as within individual companies. The benefits of the open systems based Architecture approach include both capital and life-cycle cost savings. Capital savings arise from the ability to competitively procure advanced intelligent equipment from a variety of vendors and have that equipment interoperate. Life-cycle savings arise from the ability to effectively integrate systems from different vendors and be able to maintain them through a long term life-cycle. Open systems architecture enables the development of more uniform systems across the enterprise, which is easier to maintain than a disparate array of proprietary systems. The foundation of this new system is the IntelliGrid Architecture which is an open-systems-based comprehensive reference architecture. It will integrate intelligent equipment and data communications networks into an industry-wide distributed computing system (see Figure 11). It is the fundamental basis for enhanced system capabilities [19].

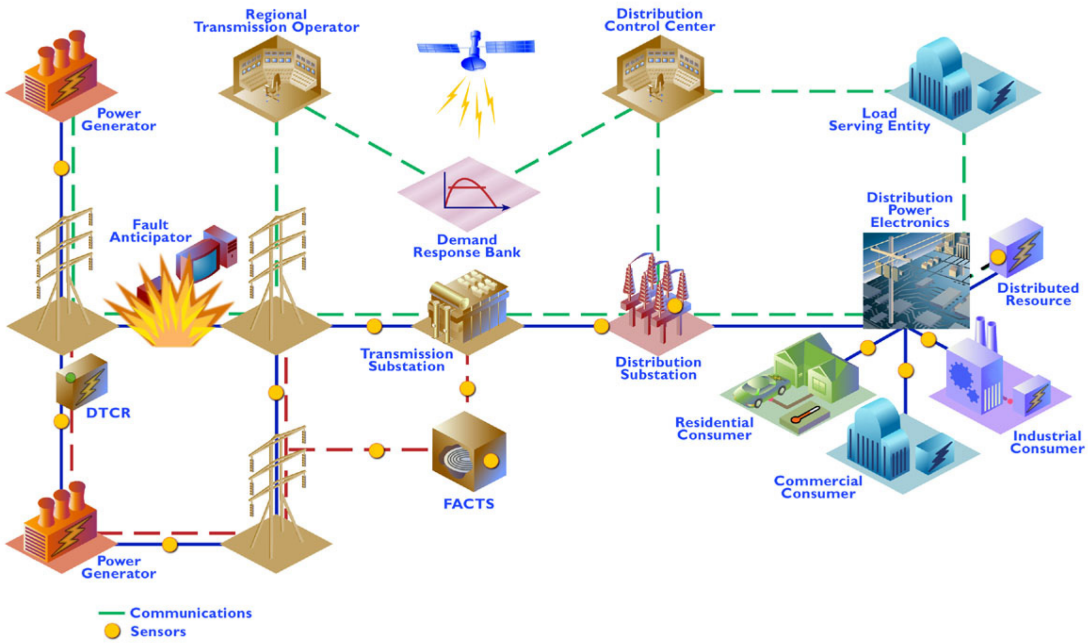

Figure 11. The vision of power system of future. [20]

4.5.2 ICT implementation in Olympic Peninsula project (GridWise)

The term GridWise was introduced at Pacific Northwest National Laboratory (PNNL) to describe the various smart grid management technologies based on the real-time, electronic communication and intelligent devices that are expected to mature in the next several years. By enabling an overall increase in asset utilisation, these technologies should be capable of deferring and, in some cases, entirely preventing the construction of conventional power-grid infrastructure in step with anticipated future load growth.

The GridWise Testbed group was assembled during year 2004 to facilitate a field demonstration of the GridWise technologies being developed at PNNL. The Olympic Peninsula was selected as an ideal location for field demonstration because the area was experiencing significant population growth and it had already been projected that power-transmission capacity in the region might be inadequate to supply demand during extremely cold winter conditions.

The purpose of the Olympic Peninsula project was to create and observe a futuristic energy-pricing experiment that illustrates several values of grid transformation that align with the GridWise concept. The stem of the GridWise concept is that inserting intelligence into electric-grid components at the end-use, distribution, transmission and generation levels will significantly improve both the electrical and economic efficiencies within the electric power system. Specifically, this project, tested whether automated two-way communication between the grid and distributed resources will enable resources to be dispatched based on the energy and demand price signals that they receive. In this manner, conventionally passive loads and idle distributed generators can be transformed into elements of a diverse system of grid resources that provide near real-time active grid control and a broad range of economic benefits. Foremost, the project controlled these resources to successfully manage the power flowing through a constrained feeder-distribution circuit for the duration of the project. In other words, the project tested whether it was possible to decrease the stress on the distribution system at times of peak demand by more actively engaging typically passive resources-end user loads and idle DG [21]. The main objectives of the Olympic Peninsula project are to:

- Show that a common communications framework can enable economic dispatch of the dispersed resources and integrate them to provide multiple benefits
- Gain an understanding of how these resources perform individually and when interfacing in near-real time to meet common grid-management objectives
- Evaluate economic rate and incentive structures and other socio-political issues that influence customer participation and the distributed resources they offer.

Constrained by finite resources, no practical demonstration can reasonably be expected to achieve all potential goals in these three areas. However, the most important desired outcomes of this effort include:

- Demonstrating how T&D capital investment can be deferred
- Demonstrating that important role that DR will play in the future and illustrating its potential benefits in the residential and commercial sectors
- Demonstrating how distributed generators can contribute benefits to the system beyond the energy they produce
- Illustrating how distributed resources can enhance the stability and reliability of the system.

The main idea of the GridWise concept is that there is no single technological “silver bullet” that will verify the best, most-effective use of power grid assets. Rather, one must integrate a broad range of new, distributed resource technologies with existing grid assets. Achieving an appreciable level of technological integration is considered to be among the most challenging objectives of the Olympic Peninsula project.

The Olympic Peninsula project was shown to be a unique field demonstration that revealed persistent, real-time benefits of GridWise technologies and market construct. The project demonstrated that local marginal retail price signals, coupled with the project’s communications and the market clearing process, successfully managed the bidding and dispatch of loads and accounted quite naturally for wholesale costs, distribution congestion and customer needs. Residents eagerly accepted and participated in price-responsive contact options and real-time price contacts were especially effective in shifting thermostatically controlled loads to take advantage of off-peak opportunities. The project demonstrated that DR programs could be designed by establishing debit account incentives without changing actual energy prices offered by energy providers.

4.5.3 SEESGEN-ICT project

The main objectives of SEESGEN-ICT (Supporting Energy Efficiency in Smart GEneration grids through ICT) consist in producing a harmonised set of priorities to accelerate the introduction of ICT into the smart distributed power generation grids, investigating requirements, barriers and proposing solutions. SEESGEN-ICT will produce policy recommendations, identify best practices and draw scenarios and roadmaps for the next generation of electric distribution network. ICT applications have been implemented for multiple purposes in this project as shown in Figure 12 [22].

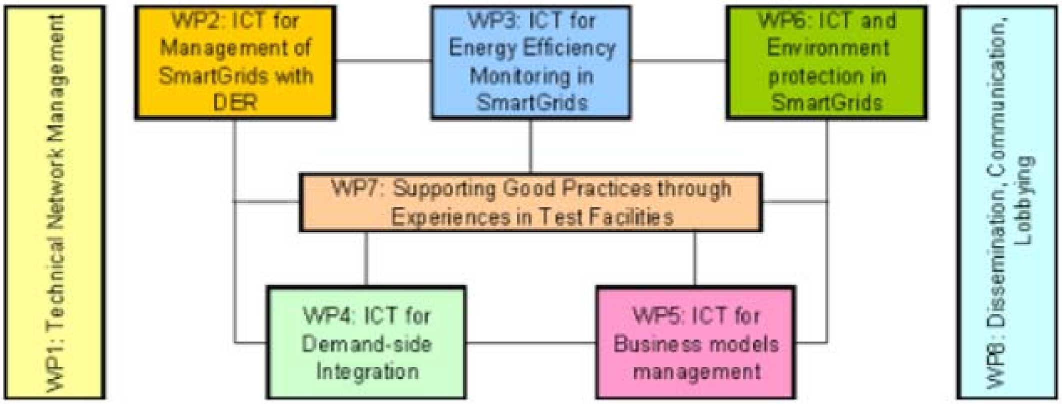

Figure 12. Structure of SEESGEN-ICT project. [22]

Each topic has been studied according to a systematic approach in order to foster actively the participation and deployment of ICT on energy efficiency goals; e.g. prioritising requirements and assessing ICT offers/needs, identifying technological and non-technological barriers, identifying solutions to barriers, prioritising policy actions and produce roadmaps for the future and formulating a complete list of recommendations to the stakeholder.

5. Smart grid visions, roadmaps and technology implemented worldwide

As a matter of fact, most of the technologies required to create a smart grid are available today. Utility companies looking forward for business enhancement are already offering DR technologies that, e.g., to detect the need for load shedding, communicate the demand to participating users, automate load shedding, and verify compliance with DR programs. Many utility companies are also implementing large numbers of smart electric meters to offer variable pricing to consumers and to reduce manual meter-reading costs [1].

Major building automation companies have smart building solutions that integrate their various heating, ventilation and air-conditioning systems. Several competing communication, however, are still vying to become the standard through which all building devices can intercommunicate. This inability to agree upon a common industry standard has delayed the vision of connecting every electric device. As expected, many white goods manufacturers are making appliances that can connect to a building's network.

Additionally, many public and private organisations have implemented energy-consumption dashboards which are custom-designed or provided by small software integrators. A variety of companies are developing microgeneration devices. A host of technology companies provide technology required to make the smart grid efficient for broadband over power lines (BPL) and radio frequency (RF) wireless communications. However, so far, nobody has been able to define an industry architecture that spans the entire smart grid from high voltage (HV) transformers at the power plant down to the wall sockets in homes and offices.

5.1 Smart grid developments in US

The steps toward a fully realised smart grid are being taken now and the potential investment has been considered substantial. EPRI estimates the market for smart grid-related projects in the US will be around $13 billion per year over the next 20 years. That comes in addition to an estimated $20 billion per year spent on T&D projects generally. More recently, a Morgan Stanley report analysing the smart grid market put current investment at $20 billion per year, increasing to over $100 billion per year by 2030. Despite these remarkable forecasts, however, smart grid deployments still represent a major departure from current utility practices. For an industry with a time honoured focus on reliability and certainty in the application of new technologies, the shift to smart grid presents a daunting challenge. However, some exciting projects are already underway.

The US is home to several consortia working on smart grid issues. EPRI's IntelliGrid program and department of energy (DoE's) GridWise Alliance are just two examples. Likewise, the nation's utilities are actively involved with approximately 80% of investor-owned utilities developing some form of smart grid, e.g. by participating in pilot studies of wide area monitoring systems (WAMS).

The energy policy act of 2005 (EPAct) in US introduced mandatory reliability standards and required state regulators to investigate advanced metering, time-based pricing and DR programs, all of which will rely on smart grid advances. The energy independence and security act of 2007 (EISA) included an entire title devoted to smart grid that provided funding for research and development (R&D) efforts, created a smart grid advisory committee and requires state regulators to consider smart grid alternatives before approving investments in traditional technologies. Standards are vital to accelerate the adoption of smart grid technologies across the utility industry. The national institute of standards and technology (NIST) is leading the standards effort and, in May 2009, published an initial list of standards that will be used in smart grid development. The government will also play a major role in the development of the smart grid through its many regulatory agencies, both state and federal. EPAct. e.g., established a mechanism for creating so called National Interest Electric Transmission Corridors to speed up the approval process for new transmission lines in heavily congested areas.

Recently, the federal energy regulatory commission (FERC) has issued an interim rate policy, by which investments in smart grid area would be included as recoverable costs in a utility's regulated rates. To create a smart grid collaborative of regulators at the state and federal level, FERC has also joined with the national association of regulatory utility commissioners. These are few examples in the role of advisor, regulator, policy-maker or even banker, the government holds tremendous influence over the course of smart grid development [23].

The potential economic and environmental advantages of a smart grid can not be overlooked. A recent PNNL study provided homeowners with smart grid technologies to monitor and adjust the energy consumption at their homes. The average household reduced its annual electric bill by 10%. By deploying this approach widely, the peak loads could be reduced on utility grids up to 15% annually, which equals more than 100 GW, or the need to build 100 large coal-fired power plants over the next 20 years in the US alone. This could save up to $200 billion in capital expenditures on new plant and grid investments and take the equivalent of 30 million autos off the road [1].

5.2 Smart grid developments in China

Electricity consumption in China has been growing at an unprecedented rate since the year 2004 due to the rapid growth of industrial sectors. Serious electric supply shortage during year 2005 had affected the operation of many Chinese companies badly. Since then, China has very aggressively invested in electricity supply business in order to fulfil the demand from industries and hence securing continuous economic growth. In addition to increase generation capacity, it is equally important to improve distribution networks and utilisation. In the last few years, the country has focused to expand T&D capacity and reduce line losses by uplifting transmission voltage and installing high efficiency distribution transformers. In addition to physics-based technological improvements, smart grid offers the possibility to very effectively manage utilisation and lead to very substantial energy saving. After US and Europe, China has also announced an aggressive framework for smart grid deployment.

Owing to energy-based nature of the present gross domestic product (GDP) growth, China's energy demand in the recent years has increased substantially. As a result, China's electricity industry has been growing at the fastest rate in human history. Installed generation capacity has run from 443 GW at end of year 2004 to 793 GW at the end of year 2008. Increment in these merely four years is equivalent to approximately one-third of the total capacity of US, or 1.4 times of the total capacity of Japan. During the same period of time, power consumption has also raised from 2,197 TWh to 3,426 TWh. Being the medium for delivering electricity to users, this rapidly increasing demand presents a serious challenge to the capacity, reliability and efficiency of the grid system.

In parallel to the economic growth aspect, the environmental problems associated with heavy industries are well known. China's heavy industrial sector is one of the biggest sources of CO_2 and SO_2 in the world [24]. The problem is further aggravated by the fact that generation resources and load centres in the country are located far apart; majority of hydropower resources are located in west, coal in northwest, but huge loadings are prevailing in east and south. It has been estimated that 100–200 GW transmission capacity will be required to deliver electricity over long distance from west to east and from north to south in coming 15 years. The existing grid structure in China (primarily based on 500 kV AC and ±500 kV DC backbones) is not sufficient to meet the existing demand [25]. Furthermore, overall T&D loss consideration is also critical because the net growth of electricity consumption will be at the magnitude of 2,000–3,000 TWh in this period of time [26]. To satisfy the needs, it is therefore necessary to establish reliable transmission circuits that can deliver electric energy across extremely long distance at low losses and developing an extra efficient distribution system for end customers.

After carrying out investigations, it has been revealed that developing and deploying ultra high voltage (UHV) technologies are mandatory for the country [26], [27]. Consequently, the government has approved a number of transmission line construction projects using UHVAC (refers to 1,000 kV) and UHVDC (refers to ±800 kV) technologies. On the other hand, to improve the overall efficiency of the grid, distribution network is another critical area that needs to be addressed. Distribution transformer core losses or no-load losses are a major component of the total T&D loss. It has been revealed that the losses due to distribution transformer can be over 40% of the total T&D losses in a typical modern grid, or about 3% of the total electricity generated [28], [29]. For 3,426 TWh consumed in China in year 2008, distribution transformers losses could be close to 100 TWh. The magnitude of these losses has attracted significant attentions and major economies including China, Europe, US, Japan, etc. have put more stringent requirements on distribution transformers losses in recent years [30]. In a general sense, efficient distribution transformers can reduce the transformer no-load losses by about 70% with respect to conventional transformer. The Jiangsu experiment has successfully verified the amorphous metals distribution transformer (AMDT) technology performance and the technology is being recommended for large scale adoption [31].

Smart grid has become an interesting topic among practitioners of electricity industry as well as in general public. It would help to enhance reliability, supply capacity and also to reduce line losses. In comparison with UHV and ADMT technologies, the principles, however, are different. UHV and AMDT are physics-based technologies that improve the components of the grid, smart grid can be viewed as a sophisticated control system for better managing resources and consumptions. After US’s “Unified Smart Grid” and Europe’s “SuperSmart Grid”, China has also announced the “Strengthened Smart Grid” plan in May 2009.

At present in China, the smart grid is focusing more on the transmission networks rather than the distribution networks. Based on the fact that coal is the main energy source and coal mines are far away from the main load centres, it is the right choice that the power grid development should be focused on the transmission networks. The project is known as the "West-East Electricity Transfer Project," which includes three major west-east transmission corridors construction. The transmission capacity of each corridor will be 20 GW by the year 2020. Through these transmission grids, electricity distributors in China will bond regional power grids in different areas of the country and improve cross-region electricity transmission ability. This will balance the power generation disparities in different regions of the country.

The state grid corporation of China (SGCC) has considered power grid construction as its core business operation at the moment. In developing power grid for transmission network, SGCC has been deploying several technologies such as WAMS and information system integration project etc. WAMS uses the phasor measurement unit (PMU) based on the global positioning system (GPS) to develop the stability of power grids. SGCC is building a WAMS and by year 2012 plans to have PMU sensors at all generators of 300 MW and above and all substations of 500 kV and above. SGCC has been deploying extensive fiber-optic networking throughout China HV substations. This network amounts to over one million kilometres of fiber-optic channels. The main features of smart grid technology implemented so far in China are [32]:

- Policy and strategy for smart grid development
- Latest T&D upgrades and developments to improve grid connectivity, capacity and efficiency
- Developing interoperability and standards to improve the connectivity of the grid components
- Preparing the engineering workforce for the emergence of the smart grid technologies
- Developing smart metering and AMI
- Management platforms, integration and security of smart grid technologies
- Renewable energy integration and environmental issues related to it
- Large scale EV grid requirements.

According to SGCC, China's smart grid plan can be divided into three stages [33]:

(1) Planning and testing (2009–2010)

Major tasks at this initial stage are establishing developmental plan, setting up technical and operational standards, developing technologies and equipment, performing trial tests.

(2) Construction and development (2011–2015)

This second stage focuses on accelerating UHV, urban and rural grids construction, establishing the basic framework for smart grid operation control and interaction, achieving the projected advancements in technology and equipment production, mass deployment.

(3) Upgrading (2016–2020)

This would be the final period of the completion of the whole Strengthened Smart Grid with most advanced technology and equipment. As further details are yet to be announced, however, it is interesting to note that the Chinese smart grid framework could be different from the rest of the world. This is because of the relatively primitive structure at the distribution ends, the extensive development of UHV transmission in recent years and also the unique asset ownership and management structure in China.

5.3 Smart grid developments in India

The growth rate in India has been raised recently as its government implements reforms to encourage foreign investments and improve infrastructure and basic living conditions for its 1.1 billion citizens. However, India is losing money in the form of electric grid losses. As India keeps one of the weakest electric grids in the world, the opportunities for building the smart grid are high. Building a modern and intelligent grid is the key requirement to keep economic growth continuously. It is only with a reliable, financially secure smart grid that India can provide a stable environment for investments in electric infrastructure, a prerequisite to fixing the fundamental problems with the grid. Without having it, India will not be able to keep pace with the growing electricity needs of its cornerstone industries and will fail to create an environment for growth of its high-tech and telecom sectors.

According to statistics given by ministry of power, the T&D losses are among the highest in the world, averaging 26% of total electricity production, with some states as high as 62%. When non-technical losses such as energy theft are included in the total, average losses are as high as 50%. The financial loss has been estimated at 1.5% of the national GDP and is growing steadily.

India's power sector is still largely dominated by state utilities. Despite several attempted partnerships with foreign investors, few projects have actually been implemented. This lack of foreign investment limits utilities' ability to raise needed capital for basic infrastructure. India's grid is in need of major improvements. This neglect has accumulated in a variety of system failures:

- Poorly planned distribution networks
- Overloading of system components
- Lack of reactive power support and regulation services
- Low metering efficiency and bill collection
- Power theft.

While the government's ambitious "Power for All" plan calls for the addition of over 1 TW of additional capacity by the year 2012, it faces the challenge of overcoming a history of poor PQ, capacity shortfalls and frequent blackouts.

The Government of India in cooperation with the state energy board had put forward a road to improvement when the new Electricity Act of 2003 was announced, aimed at reforming electricity laws and bringing back foreign investment. The act had considered several important measures:

- Unbundling the State Electricity Board's assets into separate entities for generation, T&D, with the intention of eventual privatisation
- Adding capacity in support of a projected energy use growth rate of 12%, coinciding with a GDP growth rate of roughly 8%
- Improving metering efficiency
- Auditing to create transparency and accountability at the state level
- Improved billing and collection
- Mandating minimum amounts of electricity from renewables
- Requiring preferential tariff rates for renewables
- End use efficiency to reduce the cost of electricity.

India has started to put labels on the appliances with energy use to help consumers determine operating costs. Significant efforts have been made to improve energy efficiency, e.g., to increase the average energy efficiency of power plants up from 30–40%, and pushing major industries to reduce energy consumption. Without addressing the problems of investment and financial stability, India is not able to solve its inadequate grid infrastructure. Financial stability and concurrent investment only arises from lowering the enormous problems with power theft in India.

Recently, discussion has been raised that using DSM to selectively curtail electricity use for delinquent customers or neighbourhoods, while improving PQ for consistently paying customers. It might not sound like a desirable program to most American utilities, however, it may make sense in India's constrained power grid where high levels of delinquency have increased system load without revenue returns. Another motivation to build smart grid in India is its trend towards energy efficiency and increased use of renewables. India would greatly benefit from intelligent energy efficiency in the form of DR and grid-responsive appliances. [34]

6. Comparing smart grid concepts and developments worldwide

6.1 Comparison based on project-related commercial aspects

A smart grid is felt to be a necessity for the integration of DG, RES and plug-in hybrid electric vehicles (PHEVs) into the electricity grid. Utilising DSM for improvements in overall system efficiency (such as avoiding investments in peak generation) and customer tariff systems with incentives is a driver. Respondents see ageing assets as an opportunity for investments in end-of-life electricity grid renewal. However, progress in technology is a big driver and at the same time may be regarded as an opportunity for future developments. In addition, increasing flexibility in network operation by adopting DMS as well as optimisation between economic issues including profitability and regulation schemes and technical related aspects like investments and network operation are significant drivers.

The survey conducted in this report is not a benchmarking study, rather, it provide the context for understanding the similarities and differences and the levels of implementation of the smart grids concepts, architectures, and technologies specifically in Europe, and in general worldwide. Figures 13 and 14 show a comparison of few smart grid concepts and architectures.

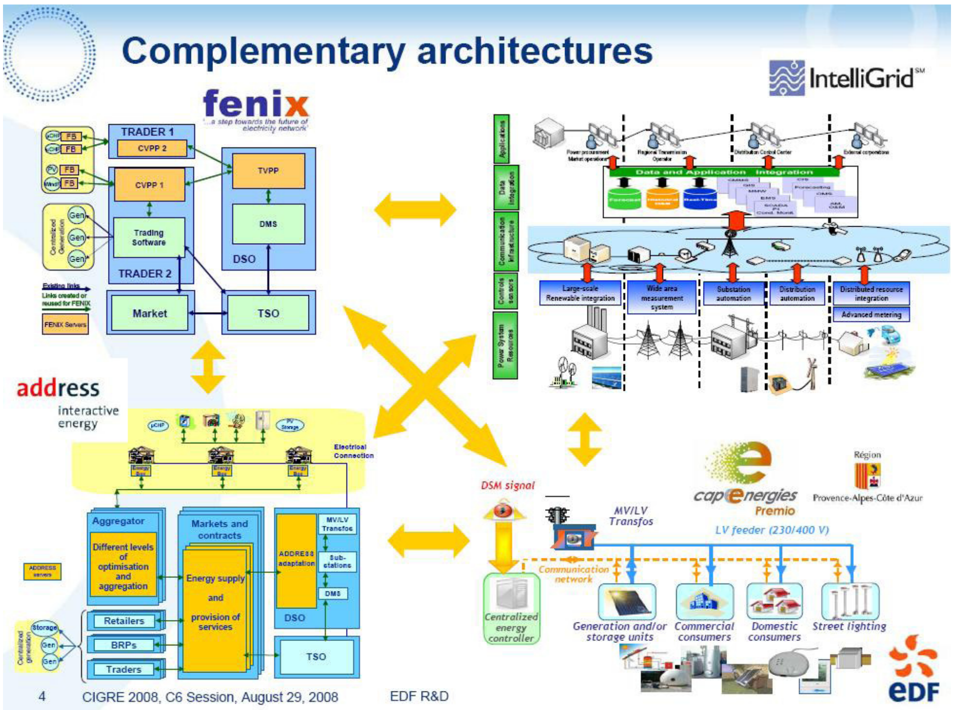

Figure 13. Examples of few smart grid related architectures.

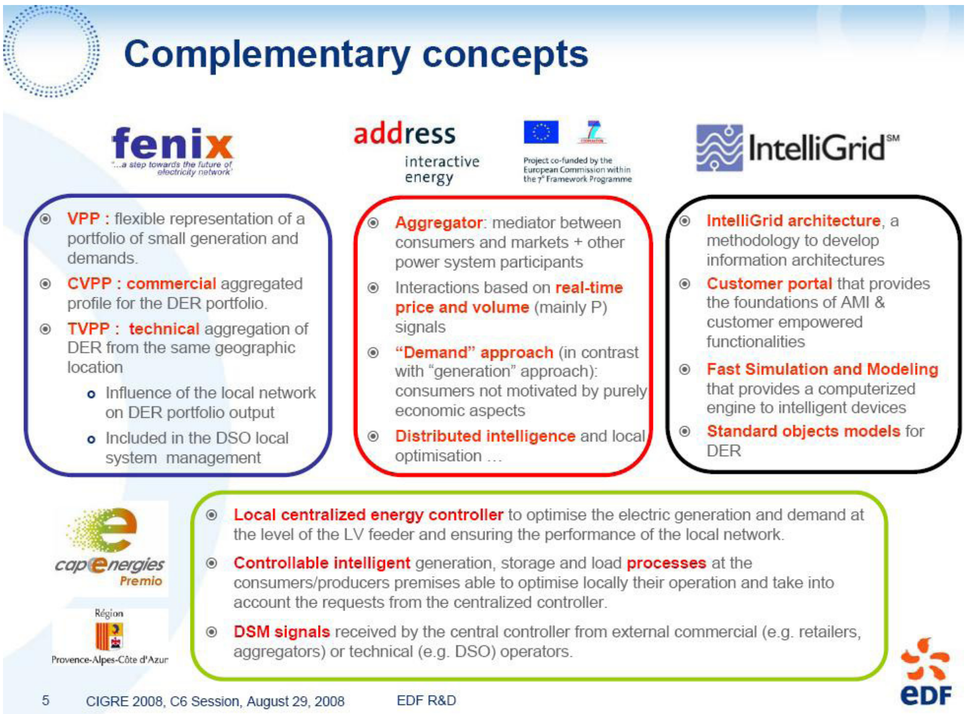

Figure 14. Comparison of the various smart grids concepts depicted in Figure 13.

In general, the ADDRESS project is building on the FENIX project. Although there are some differences between certain concepts of both projects, one could say that the ADDRESS project is fully compatible with FENIX. The one of the major differences between FENIX and ADDRESS context is regarding communication between aggregator and consumer. The communication between the trader who acts as a CVPP (and thus an aggregator in ADDRESS) in the FENIX project and the consumer is continuously monitored. On the other hand, in ADDRESS it is currently not yet decided if an aggregator will be monitoring its consumers in real time. Therefore the feasibility of continuous monitoring of a potential high number of consumers should be investigated. In case there will not be a continuous monitoring of the consumers by the aggregator, this would mean that there is no clear view on the potential and real response (acceptance and actions) of the consumer on the request or incentives sent by the aggregator. Further research should indicate if continuous monitoring is unavoidable and what the consequences will be of both options (continuous monitoring and strategies without continuous monitoring).

A distinction has to be made between two main capabilities of the equipment that is necessary to make the ADDRESS aggregator concept work: communication and intelligence. The communication deals with the signals and information that is exchanged between the consumer and the aggregator (and other power system participants when the whole playing field is taken into consideration). The intelligence represents the features of the equipment concerning algorithms, optimisation tools etc. This intelligence is in another section described as “distributed intelligence” although parts of this intelligence could (but not necessarily must) also be located at e.g. the aggregator’s level.

In FENIX, each consumer sends its load pattern for the following day. In ADDRESS the specific practical methods and procedures that will be used by aggregators and consumers are not yet decided and will be investigated in the different tasks and work packages.

Regarding the geographic aggregation and the location of the resources, there is also a difference. In FENIX, the DSO who might require a service, knows where the resource is located (node in the network). This is done through the concepts of CVPP and TVPP. First, the CVPP optimises the input of the consumers in a pure economic way and forwards this to the TVPP. The latter controls if operational constraints rise when applying the (aggregated) request of the CVPP. If this is not the case, the request of the CVPP can be fulfilled and this message will be passed through to the consumers. In case there are operational constraints (congestion, voltage constraints, current constraints), the TVPP does a second optimisation by using this technical constraints and gives feedback to the CVPP (and further on to the consumer). In the current ADDRESS architecture on the contrary, the terminology CVPP and TVPP is not used. This initially raised concerns about the compatibility of the requests of the aggregator and the technical constraints of the network controlled and monitored by the DSO/TSO. This concern should be tackled by working out a clear common understanding of the way technical constraints of the network (as monitored and gestured by DSOs and TSOs) will interact with the optimisations done by the aggregators and what the exact consequences are for the relationship between the aggregators and DSO/TSOs.

In EU-DEEP project, the concept of aggregation is wide. Aggregation will grow because of four main drivers:

- Aggregation lowers market entry barriers: in the short/medium term, it is only through aggregation that small energy consumers and DG owners can have access to the electricity market. It brings additional economic benefits to consumers and DG owners, thus increasing the value of DER and enhancing its market penetration.
- Aggregation will benefit from the rollout of smart metering, an enabler of aggregation businesses.
- Aggregation allows optimising generation and consumption through the controlled operation of a large number of DER units.
- Aggregation can combine with other energy-related services to lower their overall operating costs (ESCO, retailing).

It is by combining these features (more flexibility, lower operating costs) that aggregation will reduce the “gap to profitability” of DER units and therefore the needs for subsidies to favour their integration into the power system.

The DR was addressed in GridWise project in a new way. The idea was to implement a near-real time shadow market to provide the incentive signals that induced operation of the project’s distributed generators and DR resources. The project integrated real resources into a virtual market that allowed the resources to complete and respond to pricing signals. To avoid potentially lengthy delays and regulatory hurdles that would be encountered designing special rates for customers and implementing them in actual utility billing systems, the project’s shadow market created a debit account that customers could earn by operating household appliances in collaboration with the needs of grid. Residential electric customers were given real cash balances at the beginning of each month. As these customers responded to price signals sent from the virtual market, their cash balances were reduced or remained unchanged, depending on the value of their DRs. Quarterly, the project disbursed the remaining funds in these accounts to the participants. This virtual market environment, backed with real cash consequences for customers, allowed meaningful experimentation with various market constructs and price signals. This project represents the first limited-scale practice of a two-way clearing market with 5 minute clearing intervals at the retail level (however, in ADDRESS plan, 15 minute interval is considered).

6.2 Comparison based on technological developments

The definition of smart grid is global; however, from the operation and control perspective, smart grid technologies are varying from country to country. The actual smart grid deployment plan, however, would likely vary significantly based on the country or the region's own particular circumstances.

Taking US into consideration, while the conceptual model presented in the most recent report to NIST generic and universal, the depth of discussions about different domains varies significantly. For example, while the user-end discussions are comprehensive, analysis about transmission is relatively light. It can be explained on the basis that US system is more mature and the design orientation focuses more heavily on users and services integration (metering, renewables, electric transportation, etc.). It could also be affected by the fact that the US grids are operated by many individual players so it is difficult to enforce unified changes throughout. In China, both the focal problems and the asset structure and management are different from US.

The smart grid plan design could be different from several perspectives as mentioned earlier. The huge geographical mismatch between energy supplies and load centres in China has led to the decision to deploy a reliable interconnected UHV grid system. While interaction and services integration at user level are desirable, it is at least equally important to have a smart grid plan that can fully realise the potential of UHV transmission. Furthermore, the end-users and distribution networks in China are not as mature as most developed countries, and the penetration rate of small-scale renewables are relatively low at the moment. In fact, growth of renewable energy in the country is primarily driven by large-scale projects that do not directly connected to end-users. Given these conditions, it is expected that initial stages of the Chinese smart grid plan will focus on the ability of controlling bulk electricity transfer efficiently, and then moves towards end-users and services integration in the next stages when the users are becoming more ready. In other words, it will likely start with transmission-centric control that effectively manage connectivity and gradually enhance itself by adding discrete control and services capabilities at distribution and end-user levels. Hence, the deployment plan and technology roadmap for the Chinese Strengthened Smart Grid will likely show considerable dissimilarities in relation to the US Unified Smart Grid. The development of smart grid in Europe is driven by multiple factors, of which some are generic and some are unique. As in most of the developed economies, many HV grids in Europe were built a long time ago. Obsolete design and ageing issues have put limitations for these grids to serve the energy needs today. Another remarkable factor in Europe is energy security. As a matter of fact, Europe is relatively deficient in traditional fossil energy resources and therefore has high reliance on import. In year 2006, 83% of oil, 55% of natural gas and 58% of hard coal consumed by EU were imported. Russia is a very major supplier and countries in Middle East and Africa are also playing various roles.

When political conflicts or instabilities arise from time to time, energy supply in Europe could be seriously disturbed. In order to reduce the risk, Europe has a specific need to develop complementary energy supply. This partially explains why Europe has been running ahead of the world in terms of renewable energy deployment. The other well recognised driver is climate change. To mitigate the issue, EU has made strong commitment to reduce CO_2 emission; the European parliament has proposed the targets of reducing EU's CO_2 emission by 30% for year 2020 and 60-80% for year 2050. To reach these targets, the European grid indeed needs to be "reinvented" to prepare for 100% renewable electricity in the year 2050.

It is interesting and worthy to note that visions of the smart grids in Europe and China have many similarities, e.g., a large capacity, highly interconnected backbone as reliable carrier, added on with decentralised interactive blocks that could conveniently serve users. However, due to differences in historical developments, the sequence of deployment is varying in these two countries. As a matter of fact, Europe has already installed with large capacity of renewable generation today, whereas China is starting off with both UHVAC and UHVDC. Nevertheless differences are there, it is clear that there are many areas of common interest including but not limited to technology development, system engineering and best practices in operation. [32].

Let us compare Indian grid with one's in US. The Indian national grid was not designed for high capacity, long-distance power transfer as is the case in the rest of the world. India needs to interconnect regional grids as has already been practiced in US. Although coal and hydro-electric potential has peaked in many parts of India, there are still several regions with excess capacity. Having large wind potential and increasing wind power capacity in the southern and western parts, the need to improve transmission infrastructure has been realised. Unfortunately, the regions are generally sectionalised with some asynchronous or high voltage direct current (HVDC) links allowing for minimal power transfer as is the case in US The major difference is that India's transmission grid only reaches 80% of its population, while the transmission grid in the US reaches over 99% of its population.

6.3 Comparison based on implemented government policies

Smart grid technologies development is an important part of the ETP initiative and is called the SmartGrids technology platform. The SmartGrids ETP for electricity networks of the future started working in year 2005. The main objective is to formulate and promote a vision for the development of European electricity networks looking towards the year 2020 and beyond.

In US, with the provision of the energy independence and security act of 2007, support for smart grids has become federal policy in year 2007. A funding of $ 100 million per fiscal year from year 2008–2012 has been approved, establishing a matching program to states, utilities and consumers to build smart grid capabilities and creating a grid modernisation commission to assess the benefits of DR and to recommend needed protocol standards. In the directions of the policy, the NIST will coordinate the development of smart grid standards, which would then promulgate through official rulemakings. Smart grids received further support with the provision of the American recovery and reinvestment act of 2009, which set aside $11 billion for the creation of a smart grid.

Within the scope of its current five years plan, China is developing a WAMS and has plans to install PMU sensors at all generators of 300 MW and above and all substations of 500 kV and above till the end of year 2012. All generation and transmission systems are strictly controlled by the state, so standards and compliance processes are rapid. Requirements to use the same PMUs from the same Chinese manufacturer and stabilisers conforming to the same state specified are strictly adhered to. All communications are via broadband using a private network, so data flows to control centres without significant time delays.

7. Implementing smart grid technology in Finland

7.1 Existing features of smart grid technology

Developing the energy infrastructure towards smart grids is a longer term national objective, with smart meter rollout being one of the first steps. Considerable amounts of both public and private funding are allocated to smart grids R&D. Energy security improvement through energy efficiency is an acknowledged goal, but generally the discussion and policy measures on energy security seem to be more emphasised in the production side issues, i.e. nuclear power and renewables. Utility companies are already implementing smart devices in various ways. The smart technologies and the practices can impact the operation and overall health of the grid including the following:

- Real-time situational awareness and analysis of the distribution system can drive improved system operational practices that will, in turn, improve reliability
- Fault location and isolation can speed recovery when outages do occur by allowing work crews to drastically narrow the search for a downed line
- Substation automation (SA) enables utilities to plan, monitor and control equipment in a decentralised way, which makes better use of maintenance budgets and boosts reliability
- Smart meters[1] allow utility customers to participate in ToU pricing programs and have greater control over their energy usage and costs
- SCADA/DMS put more analysis and control functions in the hands of grid operators

[1] Smart metering regulation in Finland only covers electricity so far. A new electricity market act (66/2009 act on electricity supply reporting and metering) came into effect 1 March 2009 and requires that by 2011, all over 3x63 A connection points must have remotely readable hourly metering.

- Voltage control, through reactive power compensation and the broader application of power electronics, increases transmission capacity of existing lines and improves the resiliency of the power system as a whole [23].

7.2 Challenges faced in implementation

Smart grid is a promising platform for future electricity networks, however, many challenges are faced to implement this technology. The dire need of the time is that different market players should combine their efforts and concentrate on making the technologies and infrastructure possible for smart grid implementation as well as finding the sources of financing and returns. Different surveys have been conducted across the world to estimate the readiness of the industry and energy consumers for the smart grids [35]. One-half of the utilities surveyed in the recent Pacific Crest Mosaic smart grid survey named cost as the strongest barrier to smart grid projects within their organisation. Technology immaturity is also a key barrier to smart grid projects but is rated a "top" barrier for fewer respondents. Here are the most popular answers [35]:

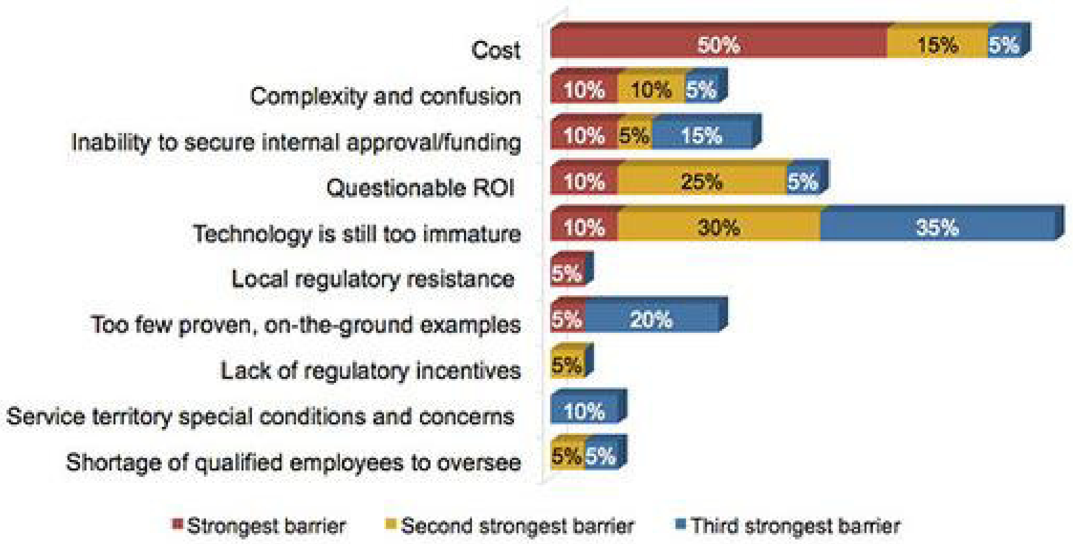

Figure 15. Statistical analysis of the barriers in the path of smart grid implementation.

The challenges can be divided into various categories as mentioned below [35]:

7.2.1 Technological challenges

The management of smart grid systems will require the use of a highly capable communications network that can provide guaranteed levels of performance in regards to bandwidth and latency. An extension of communications coverage to the distribution network can support a variety of distribution automation functions including the control of switch gear to achieve rapid restoration and self-healing properties. It now becomes possible to extensively monitor assets such distribution transformers and to actively manage feeder voltage profiles with automated tap changes or some other means.

The dilemma of choosing the most suitable communication standard at both local and wide area network levels has bothered decision makers, vendors and regulators since the development of automated meter reading (AMR) technology introduction. The initial alternatives included transition from mobile to fixed standard. The current debate includes broadband, RF and PLC standards. While the question is still opened, the RF standard seems to gain popularity. The next wave of selecting an appropriate communication technology for smart grids is centred on three groups of competing technologies. The first group is the current set of technologies (RF, PLC and broadband) that are constantly improving in terms of bandwidth, latency and internet protocol (IP) capabilities. The second group is the advanced communication technologies (3G, GPRS and Wi-Max). The future of these technologies is a highly debated issue. However, the GPRS standard is favoured in Nordic countries. The third group of technologies focuses on customer interaction and service provision through an existing internet connection. In this model, a meter is essentially replaced with a data server at home that acts as a "virtual meter". This meter will be linked up with a customer’s personal computer as an interface and will provide the requisite home area network (HAN) functionality. By the year 2014, full smart metering penetration with no more than 20% exception, when the user has max. 3x25 A main fuses, or over 3x25 A main fuse but the use is no more than 5000 kWh/year [36].

The regulatory push is strong for smart metering in Finland and its impact will be high in the year 2014 when smart meters are required to be installed at all end-users. Also utilities have started implementing their smart meter rollouts swiftly, with well over one million meters at place (with around two million left to be installed). While the technology side seems to be growing because of the regulation, the service side is still ambiguous from the technical, market model and regulation point of view. The most important question at this point is the huge amount of metering data coming from end-users (now stored by DSOs) available to all relevant actors who can make end-user services (and energy savings) with it and at what cost and restrictions? Who will pay the better service and who will pay for the new building systems integrated to the meter and related controls? Although the electricity smart metering rollout is well on its way, many utilities are still uncertain how to use the technology and data in order to reap the benefits of the investment demanded by the regulation. In recent years, there have been a few AMR solutions providers, mostly to industry, commercial and service sectors and now some ready service applications have emerged also to the consumer sector. Rather than in-home displays, the Finnish AMR and smart metering end-user services are more leaning towards web-based applications [36].

The distributed energy generation is partly weather-dependent and non-scheduled (in case of wind or solar generation). This fact brings certain challenge in regards of controlling the variable energy flow. The extensive distribution network is an enabler for DG (network must be located closer). The cheap and simple interconnection of DG is a requirement for DG profitability; however, DG typically requires major investments to the network. The DG and RES units are promoted in many ways and they are getting much publicity in many cases, however, network operator may have a risk of bad publicity when stating requirements for it. Moreover, there is a risk of oversizing the amount of DG in distribution network and the competence of network operator is essential in this sense. As the penetration of DG increases, more advanced control of the power system is required to maintain system reliability. These controls can include more efficient use of transmission, use of DR and energy storage [37], [38].

Some automation functions can already be introduced to current distribution grids without significant changes, e.g. fault diagnosis, fault location and service restoration. However, there is dire need to develop new automation functions e.g. distribution state estimation, voltage and reactive power control and network reconfiguration for improving hosting capacity of DG and its efficient control.

In order for massive penetration into current grids to take place, energy storage technologies must become cheaper. Until that time, such technologies will remain a barrier for smart grids. This is a great challenge for start-up companies, as new technology, if adopted system-wide, will open almost untapped marked of energy storage solutions. A lot of energy storage technologies are being tested nowadays.

7.2.2 Economical challenges

The new technologies introduced by smart grid, such as low-cost communication and control technologies can drive new economic models that can challenge the responsiveness of regulators and legislators. Developing the concept of VPP, introducing active DR and the role of aggregators can be one of the big challenges for future energy markets. Some of the business models proposed above may not be able to operate effectively under existing market models. An entrepreneur that operates his own DG can certainly sell the real power, but would struggle to secure an income stream from benefits such as improved voltage profile, reactive power support, or the relief of a distribution or transmission constraint.

Introduction of smart grid platform will eventually make electricity more reliable, efficient and cleaner. It may also become cheaper. But what would it cost to actually build it and how much would it save for all market players? That’s a tough question to answer at the moment. It is difficult to put a price tag on a new grid and almost impossible to count potential savings.

7.2.3 Regulatory challenges

The measure of the capacity for devices from various manufacturers to work together is known as interoperability which is vital to the realisation of a network-based smart grid, and the key to interoperability are standards. Indeed, the entire smart grid proposition is predicated on open communications between the "smart" devices using common protocols. IEC 61850 is an "open source" alternative to DNP3 and other proprietary protocols that has been adopted rapidly since its introduction. However, for various reasons it has not penetrated the North American market to the same degree as in other parts of the world. Other standards will be integral to smart grid deployments of various kinds. In the near term, however, it might be especially important for equipment vendors across the electricity value chain to supply "multi-lingual" devices that can communicate using standardised protocols, preferably more than one.

There is a need for a predictable and transparent regulatory framework for the European electricity market. An appropriate return as a basic prerequisite for investment is possible and recommendations are given to harmonising rules across Europe as far as possible. The governments and regulatory authorities should be called upon to work together towards an optimised business model for all parts of the value chain, from generators to consumers, so as to minimise total costs. The current economic crisis provides extra motivation to accelerate the process, because electric grid infrastructure is the 'backbone of the economy' and as such, one of the best places from which to kick-start the recovery. Regulators need to take appropriate measures to support the development of smart grids, allowing a fair rate of return when DSOs contribute to meeting efficiency and RES targets. These measures should lead to generally lower energy bills for customers. [7].

In Nordic countries, there are about 500 DSOs, out of which the larger DSOs are supplying about 50% of the customers. It might be a bit challenging for small DSOs to handle smart grid issues and implementing new technology, especially due to the complexity of rules and regulation of the present electricity market. To overcome the future risk concerning small DSOs attitudes, the national energy /electricity associations should have to play a very important role.

Major changes in MV and LV network architecture are not expected by all DSOs. The expected changes will strongly be correlated with the incentive scheme for renewable and DG applied in each country. Bidirectional flows of electricity at distribution level are expected to still be an exception. The power will flow mainly in the usual top-down direction (from transmission to distribution). The power flow from distribution level to the overlying level will only occur on specific spots and for limited durations. Future distribution network operation is still an issue and it can be expected that MV network will be more and more operated like a transmission network. DG developments will influence future networks investments and the expected installed capacity for DG will be a criterion in network dimensioning.

The expected mass introduction of PHEVs gives rise to the question what challenges DSOs expect in facilitating the network integration. Integrating the charging EVs in electricity networks does not require any new technology to be developed, but requires implementation of the existing technology. The existing European electricity infrastructure can be used in most of the countries for charging vehicles. If cars are charged at night even a standard household socket (16 A) would be sufficient. The grid is robust enough to allow a certain number of EVs (e.g. 10% of market share) to charge simultaneously without any severe impact on the network in off-peak time.

It is revealed from the survey that development for electricity distribution network for EVs is not an urgent issue to be considered. However, more discussion in this regard will be beneficial [7]. Advanced energy storage devices are used in some cases in DSOs operation, however, it is not clear yet that DSOs will be interested to utilise advanced storage devices in their operations. Advanced technologies enabling the island operation of parts of the electricity distribution network are occasionally implemented, but island operation of parts of the distribution network is not yet expected by all DSOs. Almost 50% of the responding DSOs expect electricity demand to increase more than in the previous years despite the increased energy efficiency due to substitution of other sources of energy. The existing centralised generation mix will still remain the key factor for energy balance. It must be flexible enough and work in parallel with the decentralised power in order to cover the electricity demand.

7.3 Adopting smart grid technology

The DSOs will install smart metering devices for residential customers and most DSOs plan to invest in customer awareness initiatives of energy consumption. Smart meters are an essential arm of smart grids and the only way of achieving effective DSM with all the added benefits [7]. DSOs may themselves benefit from smart metering systems. The potential benefits come from remote operation, for instance through lower meter reading costs, remote disconnection and connection etc. Other potential benefits result from improved knowledge of physical displacement of energy flows and increased load management capability and so on. In other words, improved data flows and communication may allow DSOs to improve how they run their systems, identify outages quicker and reduce losses to some extent [2].

Building a technology-enabled smart electricity grid can help offset the increase in greenhouse gas emissions in many different ways, e.g.

- Reducing growth in demand of electricity by enabling consumers to monitor their own energy consumption, with a goal of becoming more energy-efficient
- Provide more accurate and timely information to consumers on electricity variable-pricing signals, allowing them to invest in load-shedding and load-shifting solutions and to shift dynamically among several competing energy providers based on greenhouse gas emissions or social goals
- Broadcast DR alerts to utility companies to reduce peak energy demand and the need to start reserve generators
- Provide remote energy-management services and energy-control operations that advise customers, giving them the choice to control their homes remotely to reduce energy use
- Enable and encourage electrical equipment manufacturers to build energy- efficiency, management, and data-integration capabilities into their equipment
- Encourage home and building owners to invest in highly efficient, low-emissions microgeneration technologies to supply some of their own energy and offset peak demand on the electric grid, thus reducing the need for new, large-scale power plants
- Create VPPs that include both distributed power production and energy-efficiency measures
- Accelerate the introduction of PHEVs to provide temporary electricity storage as well as incremental energy generation to offset peak demand on the grid
- Necessary measures taken to delay construction of new electricity-generation and transmission infrastructure
- Developing smart grid standards and architectures by forming alliances and partnerships
- Making plan for the financial impact of the smart grid on their organisations.

It is worthy to note that network operator business is traditionally conservative. The technology needs to be mature enough when taken into use. Taking incompletely matured smart grid technologies to use and resulting in PQ problems or major blackouts would mean a step backwards for smart grid deployment. The network companies are responsible for their network and customers and they would like to see tested and piloted solutions before they are willing to take new techniques to their network.

8. Summary

The objective of this report was to compile various smart grid concepts, architectures, and details of associated technologies implemented worldwide. The survey was based on initiatives taken by and description of projects conducted in Europe and US. The report presented drivers, visions and roadmaps to develop smart grids in Europe, US, China and India. The survey encompassed various smart grid concepts, i.e. development of VPP, AD in consumer networks, DER aggregation business, active distribution network and ICT applications to develop intelligent grid. The comparison was carried out on the basis of commercial, technological and regulatory aspects. In addition, the existing features of smart grid technology and challenges faced to implement it in Finnish environment were addressed. The key points are described below.

In recent years, the energy deficiency has been faced in many countries which does not only impact economics, society and development of the country, but also results in the global warming. Energy demand is exponentially increasing worldwide and energy saving has become a dire need of the times. Large scale development of RES, e.g., wind and PV power generation has got special attention because they are environmentally friendly and do not emit greenhouse gas. However, integration of RES into existing power network in future may bring many technical challenges associated with PQ, system reliability and security.

The traditional power grid is based on centralised generation plants that supply end-users via long-established, unidirectional T&D systems. But times are changing and today's demands for increased power supplies with higher reliability from cleaner and preferably RES cannot be met with today's grid infrastructure. We need an intelligent system that can receive power of all qualities from all sources, both from centralised and DG and deliver reliable supplies on demand to consumers of all kinds.

Climate change, ageing grid infrastructures, reducing network losses and new power generation technologies are driving the need for the traditional power grid to undergo significant adjustments. To operate the power systems under new conditions, the smart grid concept has been proposed by integrating RES, DG, energy storage, DR, intelligent instrumentation, self-healing technologies and ICT for continuous real-time monitoring, asset management and control of electric grid capable of two-way flow of both power and information.

The energy challenges that Europe is now facing are changing the electricity generation landscape. The drive for lower-carbon generation technologies, combined with greatly improved efficiency on the demand side, will enable customers to become much more inter-active with the networks. In this context, initiatives have been taken by EU and IEA to cope with the challenges associated with future energy demands. The ETP SmartGrids was set up in the year 2005 to create a joint vision for the European networks of the year 2020 and beyond. The platform includes representatives from industry, T&D system operators, research bodies and regulators. It has identified clear objectives and proposes an ambitious strategy to make a reality of this vision for the benefits of Europe and its electricity customers. The main objective of IEA DSM Task XVII is the integration of DSM, DG, RES and energy storages and investigating how to achieve a better integration of flexible demand with DG, energy storages and smart grids. This would lead to an increase of the value of DR, DSM, DG and a decrease of problems caused by intermittent DG (mainly based on RES) in the physical electricity systems and at the electricity market. The EEG proposes a nine year European RD&D programme initiated by electricity T&D network operators to accelerate innovation and the development of the electricity networks of the future in Europe, a so-called smart grid. The smart grid will be a user-centred, market-based, interactive, reliable, flexible and sustainable electrical network system.

Various smart grid concepts and architectures have been developed based on the projects initiated is Europe and US. The FENIX project was based on development of VPP concept, the ADDRESS project is based on the concept of development of active demand in consumer networks, EU-DEEP project was based on the concept of development of DER aggregation business, ADINE project main concept is the development of active distribution network, IntelliGrid program, GridWise, SEESGEN-ICT projects were based on the concept of ICT applications to develop intelligent grid.

In US, several consortia are working on smart grid issues and developments. EPRI's IntelliGrid programme and DoE's GridWise Alliance are few examples of it. The nation's utilities are actively involved with approximately 80% of investor-owned utilities developing some form of smart grid, e.g., by participating in pilot studies of WAMS. At present in China, the smart grid is focusing more on the transmission networks rather than the distribution. Based on the fact that coal is the main energy source and coal mines are far away from the main load centres, it is the right choice that the power grid development should be focused on the transmission networks. Through these transmission grids, electricity distributors in China will bond regional power grids in different areas of the country and improve cross-region electricity transmission ability. This will balance the power generation disparities in different regions.

In India, the growth rate has been raised recently as its government implements reforms to encourage foreign investments and improve infrastructure and basic living conditions for its 1.1 billion citizens. However, India is losing money in the form of electric grid losses. As India keeps one of the weakest electric grids in the world, the opportunities for building the smart grid are high. Building a modern and intelligent grid is the key requirement to keep economic growth continuously. It is only with a reliable, financially secure smart grid that India can provide a stable environment for investments in electric infrastructure, a prerequisite to fixing the fundamental problems with the grid. Without having it, India will not be able to keep pace with the growing electricity needs of its cornerstone industries and will fail to create an environment for growth of its high tech and telecommunications sectors.

Smart grid is a promising platform for future electricity networks; however, many challenges are associated to implement this technology. The dire need of the time is that different market players should combine their efforts and concentrate on making the technologies and infrastructure possible for smart grid implementation as well as finding the sources of financing and returns. Different surveys have been conducted across the world to estimate the readiness of the industry and energy consumers for the smart grids. One-half of the utilities surveyed in the recent Pacific Crest Mosaic smart grid survey as the strongest barrier to smart grid projects within their organisation. Technology immaturity is also a key barrier to smart grid projects, but the cost issue is the major one.

To manage smart grid systems effectively, the use of a highly capable communications network will be a pre-requisite that can provide guaranteed levels of performance in regards to bandwidth and latency. An extension of communications coverage to the distribution network can support a variety of distribution automation functions including the control of switchgear to achieve rapid restoration and self-healing properties. Interoperability is defined as the measure of the capacity for devices from various manufacturers to work together which is vital to the realisation of a network-based smart grid, and the key to interoperability is known as standards.

The expected mass involvement of EVs gives rise to the question what potential challenges will be expected by the DSO in facilitating the network integration. Integrating the charging of EVs in electricity networks does not require any new technology to be developed, but requires implementation of the existing technology. The existing European electricity infrastructure can be used in most of the countries for charging vehicles.

9. Conclusions

Smart grid is a new idea for electricity networks across the Europe. Smart grids are customer-driven marketplaces and this technology provides cost-efficient grid and market connection for consumers and DG. Smart grids enable efficient operation of centralised and DG, offer services to promote consumer level energy efficiency and guarantee uninterrupted and high-quality supply of energy. Traditional grid includes centralised power generation and at distribution level one-directional power flow and weak market integration. Smart grids include centralised and distributed power generation produced substantially by RES. They integrate distributed resources (i.e. generation, loads, storages and electricity vehicles) into energy markets and power systems. Smart grids can be characterised by controllable multi-directional power flow. Smart metering has been seen as an essential part of the vision of smart grids. Remote readable energy meter is being developed to be intelligent equipment (i.e. interactive customer gateway) including, in addition to traditional energy metering, different kind of new advanced functions based on local intelligence and power electronic applications. This gateway as part of smart grids opens possibilities for network companies, energy traders and service providers to offer new kind of added-value services to end-customers. The major objectives of smart power networks are to increase the efficiency and to maintain safety and reliability of the European electricity networks by transforming the current electricity grids into an interactive (customers/operators) service network and to remove the technical obstacles to the large-scale installation and fully integration of RES.

DER can bring more to the electrical system than merely their energy content: they bring value as network replacement and may deliver system services. The DER network value is not explicitly allowed within existing regulatory frameworks: it requires upgrading metering functionalities. DER may also supply new energy services, enabled by integration schemes linking individual load and generation units. Small energy consumers and producers can thus be given indirect access to energy markets. This is a stepping stone towards the smart grid era, where every energy producer and consumer is interactively connected to the electric system. The utilities will experience lower distribution losses, deferred capital expenditures and reduced maintenance costs. The consumers will gain greater control over their energy costs including generating their own power, while realising benefits of a more reliable energy supply. The environment will benefit from reductions in peak demand, the proliferation of renewable power sources and a corresponding reduction in emissions of CO_2, as well as pollutants such as mercury.

As Smart grid ideas are promoting quickly, manufactures must become more comfortable with taking risks and applying their technologies to new applications. Rather than wait for the perfect IT solution or comprehensive standard to be developed, companies should expedite taking their solutions to market for testing and vetting. The core technology and communications standards that will enable widespread smart grid adoption are currently being developed. Once protocols are established, they will be built into a capital infrastructure (e.g. power plants, substations, buildings, power lines) that has a useful life of over 30 years. This is a much longer than the traditional ICT solution lifecycle. The technology needs to be mature enough when taken into use. Taking incompletely matured smart grid technologies to use and resulting in PQ problems or major blackouts would mean a step backwards for smart grid deployment.

Europe and China should work closely together to synergise from the knowledge and experiences in HV or UHV transmission, technological breakthrough and economy of scale could be achieved much faster. Real large scale deployment and hence enormous energy saving and superior interconnectivity would then become feasible in Europe, Asia, and the rest of the world. Besides economical and technological factors, there are, of course, some more barriers to overcome. EU member states have not yet agreed on an EU-wide energy policy, conflicts due to diversified asset ownerships and rights, etc. Nonetheless, the recent movements towards sustainable electricity systems in Europe, China and US are opening up a new horizon for energy conservation and climate change mitigation. Nevertheless, extensive international cooperation is mandatory in order to make this bold evolution successful. The global movement towards smart grid is a milestone in the history of electricity industry. While the conceptual framework of smart grid is universal, implementation plans for different regions will show certain diversities because of unique regional challenges and priorities. These diversities, on the other hand, provide the opportunity for the regions to share a wide spectrum of experiences and results and eventually lead to an optimisation at global scale.

The implementation of smart grid is consisting of more than any one technology and the benefits of making it a reality extend far beyond the power system area itself. The transition from the grid we know today to the future grid will be as profound as all of the advances in power systems over the last hundred years, but it will take place in a fraction of that time. As a matter of fact, this transition will not be so easy. The integration of various kinds of smart technologies will be essential to a functioning smart grid and the path to integration is lined with interoperability standards. Realising smart grids' potential will require a new level of cooperation between industry players, advocacy groups, the public and especially the regulatory bodies that have such immediate influence over the direction the process will take. In the end, a fully realised smart grid will benefit all stakeholders. Smart grid is an evolution towards an optimised and sustainable energy system which is more intelligent, efficient and reliable and it has positive influence on the climate change.

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