Norwegian Smart Grid Research Strategy

Prepared by
The Scientific Committee of the Norwegian Smart Grid Centre

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Foreword

The initiative to establish a Norwegian Smart Grid research strategy came from the board of the Norwegian Smartgrid Centre, which delegated the task to establish the strategy to the Faculty of Information Technology, Mathematics and Electrical Engineering at the Norwegian University of Science and Technology (NTNU).

A Scientific Committee was established for the Smartgrid Centre, and the primary objective of the Scientific Committee has been the development of this research strategy. In keeping with the objective of establishing a national research strategy, the Scientific Committee has members form a wide range of scientific disciplines and from the main academic and research institutions active in the Smart Grid area in Norway.

The large size of the committee has been necessary to ensure a wide representation. As might be expected, this has to some extent hampered progress – the research strategy has been a long time in preparation, with the first committee meetings in 2012. Still, efforts have been made to continuously update the report, to ensure that the present document gives a relevant impression of present activities and relevant research priorities.

This research strategy attempts to give a broad picture of research needs and challenges in the Smart Grid domain, as seen from a Norwegian perspective. The relevant and pressing research topics are certainly numerous, and therefore no attempt is made at prescribing a strict priority between different topics or disciplines.

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To conclude, I would like to thank all contributors to this research strategy for their efforts, both those mentioned above and their collaborators at their collaborators at their home institutions.

NTNU, June 2015
Morten Hovd

1 Some information in the report changes quite often – in particular the number of people involved in different activities listed in the table in the appendix. However, the overall picture changes more slowly that the details, and therefore this report should stay relevant for longer time.
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1 What is the Smart Grid?

Smart Grid is a term used for the electric power system of the future. However, there is no short, clear and concise definition of the concept of “Smart Grid”. The name somehow refers to the grid-part of the system (transmission and distribution of electric energy) but when it comes to practical implementation it covers much more as it will interact with almost all users (i.e., consumers and producers of electricity) of the infrastructure that the grid represents.

To illustrate the motivation, challenges and opportunities, the future power system will be characterized by significant changes in the development and operation of the grid:

- Conventional energy sources will be replaced by more environmentally friendly alternatives. In many cases, these will be developed in areas without sufficient infrastructure. These new environmentally friendly sources (wind, waves, small hydro and solar energy) will often be intermittent with significant variations over time and spatial distribution, and they are often connected to the grid through a power electronics interface.
- Transportation systems will be more based on electrical vehicles with the need for charging capabilities and will significantly increase the load especially in the distribution system. Smarter monitoring and control may be a tool to improve the utilization of the infrastructure and reduce investment.
- Electrical energy storage (such as batteries) becomes more affordable and have a number of possible small scale/large-scale applications in the power system including load/generation flexibility options.
- The number of prosumers and aggregators will increase and together with smart house, zero emission building developments might increase power quality problems in the grid as well as offer new options for enhancing reliability and flexibility.
- To enhance competition larger market areas will be the goal with more free flow of energy.
- The grid represents an aging infrastructure where it will be more challenging to upgrade and build new transmission lines. The use the existing facilities efficiently will be crucial.
- Use of new technology such as smart metering and smart sub-stations and power electronics give new opportunities for enhanced monitoring and control.
- Massive use of new technologies (smart meters and communication systems) increases the complexity of the system and will challenge the robustness and the reliability.

These challenges will require flexibility, more overview and control opportunities as the system has to be operated closer to the limits. System states must be precisely detected, classified and appropriate actions must be conducted within the time available.
Smart monitoring and control are clearly important elements of the Smart Grid. Appropriate hierarchical designs must be developed leaving the tasks to be solved at the most appropriate level in the system.

Requested flexibility will require coordination procedures between generation resources spanning different time horizons while using the flexibility the demand side may contribute with. There must be instantaneous balance between generation and load but storage options must be used to secure the supply and to make the overall use of the infrastructure better.

The Smart Grid is then the electrical power grid of the future, making extensive use of:

- Two-way communication to exchange information used to monitor, coordinate and control the system.
- New sensor- and actuator technologies to improve the detection, interpretation and to safely use the inherent margins of the system.
- To develop smart functionality to make it possible to automatically optimize system operation in order to get a safe and reliable supply of electric energy.

These short definitions give some insight into what is meant by the concept Smart Grid, they are incomplete, and do not shed any light on what technological, economic and societal challenges have to be met in order to realize the Smart Grid. Such topics will also be important research areas within a smart grid concept.

The following two chapters attempt to paint a broader picture of the motivation for Smart Grid research and the contributions of different disciplines, in order to give the background for the Norwegian Smart Grid Research Strategy.
Figure 1: Smart grid reference architecture - CEN-CENELEC-ETSI Smart Grid Coordination Group – M/490 EU Mandate.
2 Trends, opportunities and challenges motivating the Smart Grid

The electrification of society was one of the greatest engineering achievements of the 20th century, and the electrical infrastructure became one of the critical infrastructures. Electrification was based on the paradigm of centralized generation, where large scale power stations produced power that was transmitted through the power grid to passive consumers in the other end of the system. The bulk of world electricity is produced in thermal power stations where the prime mover (turbine) is driven by steam. The primary fuels (IEA, 2012) for generating the steam are fossil (about 68%, with coal as the largest) and nuclear (about 13%), which are most rationally utilized in large units, hence the need for centralized production. In Norway, hydro power constitutes about 95% of electricity production, but worldwide the contribution from hydro is only 16%. Although the power ratings of hydro power stations vary considerably depending on local conditions, hydro power has also traditionally been viewed as a centralized form of generation, most often with a need to transfer bulk power large distances from the hydro power source to the consumers. Hydro power is renewable, but the potential for increasing the worldwide contribution from its present 16% is limited. Concerns about the massive amount of CO2 that are emitted to the atmosphere by burning fossil fuels, call for a change in the way we think about production and use of electric energy, and energy as a whole.

The European Union’s climate and energy package (European Commission, 2008) includes the “20-20-20” targets of a 20% reduction of greenhouse gas emissions, a 20% improvement in energy efficiency, and a 20% share of renewable in the EU energy mix, all by the year 2020. The goal of 20% share of renewable is also established through the Renewables Directive (The European Parliament, 2009). The EU is also looking beyond 2020; Germany probably has the most aggressive approach with a goal of an 80% share of renewables by 2050, through a complete transition of the energy system, the “Energiewende” (BMU, 2012). The Renewable Directive has been made part of the EEA Agreement (Official Journal of the European Union, 2012), and Norway is obliged by this directive to increase its share of renewable energy to 67.5% by 2020, up from 58.2% in 2005.

In October 2014 EU decided on the climate and energy policy framework targets for 2030: At least 40% reduction of greenhouse gas emissions, at least a 27% improvement in energy efficiency, and at least a 27% share of renewable in the EU energy mix. Norway has endorsed these policies.

As the electrical systems became larger in step with economic growth, engineers learnt how to utilize existing infrastructure better to minimize the investments needed to accommodate increased electricity usage. However, the ageing electrical systems in the developed part of the world are now increasingly facing challenges that the systems were not designed and engineered to handle. Both in Europe and in the USA, there have been wide-area outages over the last 15 years that have been triggered by relatively minor events in parts of the system (SIEMENS, 2011), but which have however led to cascading effects, resulting in blackouts, with huge economic consequences, and with potential consequences for national security. The expected development towards larger shares of variable renewable energy (VRE) will add further challenges to system balance and grid stability. This calls for a modernization of the electrical infrastructure.
In large part because of the above mentioned concerns, the notion of a Smart Grid has been conceived, and it is now one of the trending topics in the international, including the Norwegian, power sector. Smart Grid is not only about the environment and the economy, but it also has to do with connecting the electricity sector to the digital realm. Such a smart power grid is now being brought to the foundry. In some ways, the situation bears resemblance to what we saw during the nineties when almost everyone knew that the Internet was only increasing its significance, but what it would entail in practice was still not known. The technology in the power grid must change; fossil fuels will be gradually phased out and replaced by intermittent renewable energy from e.g. wind and the sun, often in small scale and of a distributed nature. Thus, the paradigm of centralized generation will have to live side-by-side with the new paradigm of distributed generation. In addition, transportation will gradually become electrified. As the share of electric and plug-in hybrid electric vehicles increases, new load profiles will emerge, and the batteries of electric vehicles may interact with the power grid and serve as energy storage. This too calls for a new way of thinking. As the electricity sector is connected to the digital realm, we will have new and more advanced meters with a greater array of functions and possibilities. The market for household technologies, for the kitchen, bathroom or the garage will expand and include technologies that may engage with the Smart Grid to facilitate more active electricity demand response. The power industry can create new business models, novel billing methods, flexible tariffs and new services. Many businesses presently not involved with energy can find new possibilities to reorient their endeavours towards this sector as well, and traditional actors can expand their already existing business models.

2.1 The situation today

In the European Union, the 20-20-20-agenda was a strong driver for change and the 2030 targets will give further incentives. During the last 10 years, the amount of electricity produced by photovoltaic panels in Germany and Italy has increased from virtually zero to about 6% of the total electric energy produced in 2012, and the growth continues (IEA PVPS, 2013). In Norway, the share of photovoltaic electricity is virtually zero at present (2015). However, the potential for solar electricity is about the same in Southern Norway as in Northern Germany, with an annual irradiation of about 1200 kWh/m². In fact, it has been calculated based on measured data that only 0.7% of Norway’s land area would have to be covered with realistic photovoltaic power stations with present day technology to produce 120 TWh of electric energy annually (Midtgård et al., 2010). However, the potential for photo voltaic technology in a country like Norway lies mainly in its nature as a distributed source of energy, which fits well with visions of energy neutral buildings. This vision is reflected in stricter building codes, see e.g. the white paper (Norwegian Government, 2012). To achieve the goal of a zero-emission building, it is recognized that building-integrated photovoltaics (BIPV) may represent a solution for a building to harvest the energy needed (B. P. Jelle and C. Breivik, 2012). For these reasons, distributed solar photovoltaics is expected to increase also in Norway, and could potentially have a huge influence on how especially the low-voltage distribution grid is built and operated. (In 2014 the capacity of PV installed in Norway was three times higher than in 2013.) In Germany, where distributed photovoltaic power stations contribute to 70% of the photovoltaic electric energy (J. van Appen et al., 2013), utility companies are starting to adapt to the new reality; to stay competitive, they have to think of themselves as renewable energy service providers, rather than as traditional electricity providers.
Whereas solar photovoltaic power generates only about 0.5% of the world’s electricity, wind power is significantly larger with a global share of about 2.5% (IEA, 2013). About 30% of the electricity consumed in Denmark is from wind, but there are several other significant players as well, such as Portugal (20%) and Spain (18%). In spite of having some of Europe’s best conditions, Norway does so far play a very minor role in wind power, with an annual production of 1.57 TWh in 2012 (NVE, 2013), which was only 1.1% of the total electric energy production. An increase of several TWh is however expected towards the year 2020 (A.C. Bøeng, 2011) due the common Norwegian-Swedish market for electricity certificates that was established in 2012 (OED, 2012) as a means to achieve the goal of 67.5% renewable energy by the year 2020, as required by the Renewable Directive. Looking further ahead, when offshore wind may reach technological maturity, Norway could become a major supplier of wind power (NVE, 2010). This will require also a Smart HVDC Grid in the North Sea bring the offshore wind power to shore reliably with a minimum of loss, and in step with the power grids of Europe.

For plug-in electric cars, Norway has taken a lead role; in February 2015 there were more than 48000 electric cars in Norway (Norsk elbilforening, 2015), and in February 2015, 18% of new sold private cars were electric (OFV, 2015). This is quite impressive considering that the total stock of electric cars in the world was only about 750000 by the beginning of 2015 (Centre for Solar Energy and Hydrogen Research, 2015). Although this is still a small number compared to the total number of passenger cars in the world, the growth is rapid, and plug-in electric cars will influence the grid both as a new load (when charging), and also as energy storage (so-called V2G – vehicle-to-grid) in the future.

Energy storage is also seen as an important element of the Smart Grid, as it will help shape load to the intermittent production from wind, solar and other renewable sources. In Germany, a new government incentive program will contribute up to 30% of the total cost of energy storage systems when paired with solar photovoltaic power production (CleanEnergyAuthority.com, 2013). On the level of bulk transmission of electric energy, wide area monitoring, protection and control receives considerable attention; new technologies such as phasor measurement units and Flexible AC Transmission Systems (FACTS) based on power electronics will contribute to a more stable and secure transmission grid, while at the same time being able to operate the system closer to its limits, thus avoiding expensive and often controversial investments in large high voltage power lines. Increased use of advanced High Voltage DC Transmission systems not only enables renewable power from offshore wind farms to be connected the main grid, but also:

- enhances the controllability of the power flows in the power systems (SIEMENS, 2011),
- connects asynchronous power grids together,
- and enables more exchanges of power between countries and regions.

Thus, it is seen that the structure of the grid and the sources of electricity are already changing quite rapidly.

Another method that is used to shape load is demand side management that will be enabled by the introduction of smart meters and other two-way communication means between the grid operators and the consumers. Demand side management, as is implicit in the name, is to remotely manage local loads. Demand response, a close relative, is mainly focused with incentivising rather than control. The goal of DR
is to use price signals and consumption data to incentivise consumption patterns away from congested hours, or what is called peak load (commonly mornings and afternoons, where the consumers all demand high levels of electricity at the same time). The consumption information and price signals making DSM and DR possible will be aggregated in the Smart Grid, mainly by smart meters.

Ever since the Norwegian Water Resources and Energy Directorate sincerely laid a focus on implementing smart metering, or an Automated Metering Infrastructure (AMI) in the Norwegian power grid and set the deadline to 2019, an intense effort by the Norwegian grid companies was undertaken to map out and define what is meant by making the ‘Norwegian’ Smart Grid. They were the ones given the task of constructing the first piece of the puzzle that in time will become the Norwegian Smart Grid, the smart meter. The meter was from the part of the regulator defined to fulfil a range of functionality that to a large extent is comparable with that of the European AMI specifications. It shall among other things be able to report values and system reports to the grid company autonomously, measure power both in and out of the node, as well as make possible remote load control and curtailment of power in the node. These specifications were implemented by the regulator in collaboration with the power industry in regulation 301\(^2\), pertaining to ‘measuring, calculation and coordinated effort of power trade and billing of network services’, and were drafted in the summer of 2011. An overarching goal of smart metering is to aggregate new and more detailed information about the consumption in the measuring nodes. This information must be then be used to lead local consumers, grid companies and retailers towards better and smarter decisions in the power grid. Furthermore, the information will make possible a greater degree of automation and increased flexibility in the grid through demand response.

Even though the regulation is in force, the technological framework for fulfilling the introduction of smart meters is not set in stone. During 2012 the grid companies, in collaboration with Energy Norway (The industry organization for energy companies in Norway) and the regulator, laid down a considerable amount of work to interpret what the regulation would entail in technical terms. The regulation does not say anything about if or how existing solutions may be used (e.g. the Internet), or whether entirely new solutions needs to be made. In general, the regulation calls for open standards and a non-proprietary architecture. The industry itself has aimed for harmonization with the European situation and the work within EU's mandate 441, especially as security measures in the AMI needs to be state of the art – as called for in the regulation as well. Norway is well served with opting for solutions that may also “talk to” solutions elsewhere in the world. There is little reason to believe that most of the innovation on AMI will be undertaken in our particular corner of the world. Neither will eventual special concerns for the Norwegian Smart Grid be taken into account by the rest of the world. Norway has 2.7 million measuring points, a microscopic amount in global terms. This fact underlines the importance of our R&D work maintaining a broad perspective, contextualizing Norwegian particularities with international perspectives.

The development of the AMI and the Smart Grid is in a large part about updating technical infrastructure on a large scale. Consequently, one of the stakes involved is the broader social economic benefit of the nation, benefits accrued on a large scale. In this regard Smart Grid work in Norway has thus far had a strong focus on its potential benefits. In recognizing this, we need to remember that there are certain pitfalls.

\(^2\) [http://www.lovdata.no/for/sf/oe/xe-19990311-0301.html#map004](http://www.lovdata.no/for/sf/oe/xe-19990311-0301.html#map004)
which need to be avoided for any potential to be successfully realized. The research undertaken on the Smart Grid in years to come need to highlight these pitfalls, aided by perspectives suited both for asking critical questions as well as putting forward constructive solutions. For instance, how can we avoid proprietary solutions leading to a closed innovation environment? What makes industry and market actors appreciate the big picture of the Smart Grid, so that they may avoid leaving us with sub-optimal and irreversible rush-job solutions in the future? How can we promote a holistic approach, so we make certain that the new meter will be more than just an automated reader with a digital display? These are questions that have enjoyed some focus so far, for instance in the collaboration with the numerous pilot projects that have just had started. This is a fruitful way to gain fresh access to and insights into the social, economic and technical implications of the Smart Grid. This is important if the full potential of the Smart Grid should have a chance to be fulfilled in a way that makes it beneficiary to society as a whole.

2.2 Which possibilities does the Smart Grid represent?

As mentioned above, Europe has strong ambitions regarding the integration of renewable energy and dispersed generation. This is a considerable challenge with respect to maintaining the high quality of supply that customers are used to. Some of the issues that have to be dealt with are reverse power flows in the distribution grid because of distributed generation, the power quality and the continuity of electricity supply. A Smart Grid is necessary to accommodate the new renewable energy.

The Smart Grid will also ease the transition to electric transportation. When electric vehicles become common, they will lead to both an increase of the peak load in the system, and an increase in the total consumption of electric energy. On the other hand, the combined battery capacity of electric vehicles will be significant. This energy storage capability may be utilized (in addition to other forms of energy storage) to enhance the reliability and stability of the system, through vehicle to grid (V2G) technologies. A Smart Grid is needed also in this context.

As mentioned, the Smart Grid will require energy storage to accommodate larger shares of renewable, intermittent energy from the wind, sun and other sources. Energy storage will contribute to balancing of supply and load, and will also be used with power electronics converters to provide services to the grid, i.e. reactive compensation and active filtering. Other Smart Grid technologies which will manage the variability in the production from renewable sources are energy management, demand side management and more flexible interaction between thermal energy systems and the power system. The vision of these technologies is that they will contribute to a paradigm shift in the way the grid is operated; until now, production of electricity has followed the load, whereas in the future, the load may to a larger extent follow the available production from the renewable sources. One current challenge for achieving this is that the level of demand flexibility that electricity end-users are willing to offer to the grid is currently very low. The price elasticity of demand for Norwegian household customers, for example, is estimated by Ericson (2006) to be -0.02. To increase the value of response the electricity consumers may have to be approached through both educational activities and technological promotions. Also, attractive combinations of tariffs, technology installations, customer rewards, and savings options, as being offered in some parts of the USA, have proved successful in reaching and motivating the target group of electric power users. The effect of such initiatives could be considerable when it comes to increasing end-users’ participation in demand
response programs and can thus be considered an important contribution to utilizing the Smart Grid functionalities.

However, it may also be expected that the demand response will not require any action on the part of the actual consumer in the future. Intelligent energy management systems will listen to the price signal transferred by the advanced metering infrastructure, and other signals send by the system operator, and adjust energy storage and loads accordingly in order to optimize the economy and operation of the total system. Such energy management systems could operate either on the level of an individual home, or could be managing the whole microgrid of a community. New housing projects can be planned in the context of the Smart Grid and in principle be self-supplied with energy and being able to operate independently of the power grid. The microgrid will however normally be connected to the power grid at one point, but the complexity of the Smart Microgrid will be hidden for the main grid, which sees the community as a single point of load or production (depending on the amount of renewable energy being produced by the community at the moment).

The Smart Grid is also related to the reliability and quality of supply of electric energy; in which the changes in the energy system as such do not reduce the quality in spite of the challenges posed by introducing large amounts of intermittent, distributed energy. The Smart Grid can also contribute to reduce the cost of replacing fossil, centralized generation with renewable, distributed generation through better controllability and the opportunities it provides for supporting the grid in various ways.

One element of the Smart Grid that is soon to be deployed all over Europe is the advanced metering infrastructure (AMI), or smart meters. What goals and motives exist for implementing AMI will vary according to who are asked. Some of the viewpoints are summarized in the following. Smart meters will affect the energy system as a whole, and have the potential to change many of the aspects of how we relate to it. On a macro level there are hopes that new information about consumption and load patterns may contribute to making grid companies more efficient as the new overview will give them a more informed position when making decisions about day to day operations and long term investments. The market may change considerably with the implementation of the new centralized data hub which collects and makes representable all billing information from the meters. The responsible party for developing a data hub, Statnett (the Norwegian TSO – Transmission System Operator) has stated that it represents a move towards a customer-centric model\(^3\). It will create the foundation for a restructuring of the power market, where the retail companies would comprise the only point of contact to the market for the customer. As already mentioned, value chains between the various actors of the power markets would open up and become more seamless, and new possibilities for demand response, trading with aggregated power and new market models related to this would appear. New business models may arise, as exemplified above, especially on the side of the consumer where new tariff models, software and hardware can be linked to information about consumption to make the end-user into a more active and responsive part of the power market. For instance, a new model which could restructure the energy market has thrived for some time already on the Internet, the so called multi-sided platform. It “provides goods or

services to two or more distinct groups of customers who need each other in some way and who rely on the platform to intermediate transactions between them. In conjunction with the Smart Grid, the platform could be the AMI-channel, and it could for instance be provided to third party actors, like energy or service retailers on one hand, and end-use customers on the other. Such constellations already exist in the form of social media platforms like Facebook and YouTube, but they would be a qualitatively novel addition to the power market. How such constellations may change the conditions of today is still uncertain. In such a perspective, the importance of the R&D-strategy focusing on the market and its movements in order to provide us with an early idea of where we are headed becomes clear.

The first to have realized the coming changes are the technology suppliers of the grid companies. The latter has lately worked their way up to a radically new ordering competence to be able to deliver AMI as prescribed by the regulation, and now a question exists about the suppliers’ ability to answer what will be requested of them from the grid companies. Also, there is a question about whether some of the smaller grid companies have been able to follow the latest development, and how this will affect their relationship with their suppliers. In the extension of this there are predicaments that lie outside what deals merely with the relationships between grid owners and suppliers. The grid operators have met great risk and uncertainty in dealing with their AMI assignment, and it would be expected that the result of this is a smart meter that probably will not exceed the immediate demands of the regulation.

This leaves third party actors integral to drive development and innovation in the outskirts of the smart meter and the new data hub. The information made available needs services, software and hardware in order to become useful, both for macro and micro actors. To what extent technology suppliers and other third party actors are working on these challenges, what kinds of fruit the work will bear, and how we can make use of them, will all be central questions for a long time to come. This makes evident the importance of the R&D strategy to also move out of the traditional electricity sector, thus enabling it to encompass the full extent and scope of the changes imminent and the significance of them.

2.3 Challenges. Smart users, privacy, and accepting technological change

The roll-out of smart metering equipment has just barely begun, and for everyone involved the learning curve is steep. One of the most important actors in the power grid of the future is the end-user of electricity. Not only is the consumer a central part of the energy chain, but the power grid is also an inseparable part of everyday human life and the undertakings of which fills modern society life. The need to see new technologies and market models in the light of end-use of electricity as it is actually practiced becomes important if we also recognize the potential of the Smart Grid to change the way we relate to energy consumption. The user is situated in a cross section between regulation, economy and technology development, and the understanding the consequences for users resulting from endeavours in these three
areas is important for understanding changes in consumption behaviour, or the lack thereof. Simultaneously, a bottom-up perspective on users, seeking to explore everyday energy consumption is important to provide insights into how technological solutions may actually make a difference in changing consumption patterns in desired ways. If the smart gadget ends up in a drawer, as has in fact been witnessed by researchers on energy consumption (c.f. Hargreaves, 2012), it loses its influence and the potential goes to waste.

At this juncture, the knowledge level in society in general about the Smart Grid seems relatively low, and in general a slight air of negativism can in the worst cases be felt emanating from parts of the population. If this trend carries on it could have unfortunate consequences, both as negative prejudices against technologies or as unrealistic expectations of its potential. The former scenario has been duly witnessed in several other countries (like USA or the Netherlands), where tactless roll-out of smart meters without it being preceded by any kind of information in some areas resulted in the perfect climate for negativism, myths and prejudices against the new meters, in some cases even forcing companies to roll back the new meters or allowing for customers to opt-out. We have also seen tendencies at home that media sometimes favours catering to fears about the new technology’s potential as a tool for big brother (or other malicious actors) to spy on the populace by getting access to consumptions patterns6. Similarly, in the over-enthusiastic scenario we might see unfortunate expectations arise about how smart the house can become and how considerable amounts of money may be saved as a result of the new technologies. In both cases, unrealistic ideas about the technology may lead to problems of users not accepting technology later on, and should be regarded as a challenge to take seriously, perhaps mitigated by addressing the customers need for up front information. Furthermore it should be noted that while privacy may not be regarded as a challenge from a technological stand point, the issue of privacy manifesting itself as such in society could result in real problems.

Another point relates to how users end up interacting with the installed technology. We have already seen that from a technical perspective there are significant expectations to what can be achieved through automation. Perhaps users do not need to interact with the technology at all to achieve desired flexibility? The history of technology, however, suggests that users are not always interested in such solutions. There are already studies on so-called passive houses that suggest that much of the theoretical potential in terms of energy savings is spoiled by unwanted user behaviour. Similarly, what happens if users get annoyed with the automated systems? What about when there is a sudden need for large amounts of hot water at night, washing the dishes outside pre-programmed schedules or when you need the electric vehicle even though it is supposed to feed electricity to the grid from its battery at that particular moment. Chances are high that people will invent strategies to circumvent automated practice, thereby reducing the expected gains.

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2.4 Concluding remarks

In this chapter, we have discussed the Smart Grid from the perspective of connecting the electric sector to consumers in a new way through the digital realm and from the perspective of renewable energy.

A revolution in renewable energy can contribute to solving the energy situation for mankind in the long run, and will be an important part of the solution of the climate crisis; renewable energy makes a continued increase in the world’s electricity consumption possible without increasing emissions of CO₂ to the atmosphere. The Smart Grid is the technology needed to integrate intermittent, renewable energy with the electric infrastructure, while maintaining or even improving system reliability.

The Smart Grid also affects us as individual consumers. We do not yet know how technologies relating to the Smart Grid will be conceived by the society, and how the implementation of new smart grid technologies becomes integrated in existing practices. What attitudes prevail, and what does it entail for innovation, new products and markets? In what ways are new technologies incorporated in the households, and why is technology in some cases not used as initially conceived? Or worse: not used at all? Studies of society’s broader discourse and narratives about the Smart Grids as they appear in for instance the media may provide insights into these issues.
### 3 Perspectives on the Smart Grid: Research topics

Table 1 is an illustration of key disciplines required in Smart Grid research, and their interaction with different application domains within the Smart Grid. Note that the table is by no means intended to give a complete picture of the Smart Grid research, only to illustrate some important disciplines and where they are expected to contribute the most to realizing the smart grid.

**Table 1: Disciplines and domains for Smart Grid research.**

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<tr>
<th>Perspectives/Disciplines</th>
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<td>Micro grids</td>
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<td>EV integration</td>
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<td>Information and Communication Technologies</td>
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<td>Business and services</td>
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<td>User behaviour and acceptance</td>
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3.1 Perspective - Microgrids and distributed generation

3.1.1 Introduction
Today there is an increased focus in applying distributed energy resources (DER), e.g. small-scale wind and hydro power, photovoltaic etc. Distributed generation (DG) may be directly connected to the distribution grid, but could also be integrated into a Microgrid.

A Microgrid is typically a power network with a rated capacity of 10 MVA or less. The network could be isolated or connected to the local area distribution grid through a point of common coupling (PCC). The Microgrid could contain DG sources, local demand, or a mix of both. A Microgrid with a varying power generation and consumption could have a bi-directional power flow through the PCC and would change between net power production and consumption. Seen from the local distribution network the Microgrid would then act as a so-called prosumer.

Some Microgrids might have the capability of power shaving (making the power flow through the PCC as smooth as possible). They might also be able to disconnect from the distribution grid and continue in separate operation during a blackout or other severe power grid contingencies. Normally an energy storage system is required in order to obtain this capability.

Power converters are often included into the Microgrid in order to increase the flexibility and controllability. There is a number of different kinds of network topologies and control strategies for Microgrids.

3.1.2 Challenges
An increased amount of DG could strain transmission capability of the distribution grid. Even the transmission network could be overloaded, if a vast number of DG units are to be grid connected.

DG will also change the voltage profile along the power lines, as the power flow changes its magnitude and direction. If the DER has an intermittent power flow, the voltage disturbance could even cause flicker.

DG should be disconnected whenever the distribution network is disconnected. Otherwise, the DG could keep the local area network energized, a condition called islanding. Such unintended islanding conditions could be very harmful. If the distribution grid is disconnected due to a severe fault, the grid should be de-energized in order to clear the fault. The network could be disconnected in order to perform maintenance work, in which case an islanding would be hazardous. Unintended and uncontrolled island could also have a lack of power balance between production and demand, and the voltage and frequency could easily exceed the boundaries of safe operation.

A poorly designed Microgrid containing power electronics could inject voltage and current harmonics into the distribution grid.

A Microgrid in separate operation is a weak grid, and maintaining the power balance between generation and consumption could be a challenge. It could be difficult to obtain voltage and frequency stability inside the Microgrid.
3.1.3 Possibilities
A well designed Microgrid with the ability of separate operation would act as an uninterruptible power supply (UPS) for the internal load. A Microgrid equipped with power converters could also provide reactive power compensation on the distribution network.

A flexible Microgrid would dampen the power fluctuation of intermittent power sources, thereby reducing the voltage disturbances on the distribution network.

Since generation and load is integrated in a small and compact network, the need for long distance power transmission is reduced.

Microgrids can be utilized anywhere in the world. The distributed energy sources may be different, but the general principle is the same. Hence, a research on DG and Microgrids will have a global significance, not only local or national.

3.1.4 Relevant research topics
Development of new distributed energy sources and improvement of existing ones is one possible research topic. Another is investigation of renewable energy sources in a cold climate. There are several different Microgrid topologies, which could be analysed and compared. Microgrid operation and control is an important aspect. The interaction between the Microgrid and the distribution network is another important topic. Island detection is also crucial, in order to disconnect the Microgrid during fault contingencies. For the transmission system operators (TSO) the impact of large amounts of DG on the transmission network would be important.

3.2 Perspective - Integration of Renewable Energy
3.2.1 The big picture
Globally, the demand for electricity will continue to rise, due to both the necessity of lifting more people out of poverty and because of the continued rise in global population. At the same time, governments around the world acknowledge the need to reduce emissions of CO₂ to limit global warming. Besides, fossil energy is a finite energy resource, and there are concerns about the future role of nuclear power as well. The solution of these combined challenges is renewable energy, and the effective integration of renewable energy is one of the important drivers for the Smart Grid.

Norway is in a special situation regarding renewable electricity since 95% of our electric energy is produced by hydro power. A conservative attitude is therefore often adopted, and much resistance towards changing our electricity infrastructure can be observed both in the population as a whole, but also among the utilities themselves. However, 50% of the country’s energy usage is non-electrical, and some of this energy could be replaced by renewable electricity. Besides, Norway could be an exporter of renewable electricity produced by our huge wind power resources to Europe. Recently, Norway has also seen a rapid increase in its population, driven by immigration. If the pattern of immigration continues like in 2011, the population will reach 7 million in 2045, up from 5 million today, according to Statistics Norway. The increased population could lead to a higher demand for electricity also here.
3.2.2 Renewable sources of electricity

Presently, the largest source of renewable electricity worldwide is hydro power. But solar and wind power are rapidly catching up, and towards the end of the century, solar electricity may dominate the world’s electricity production—see example of PV concept in Figure 2 where PV-panels are tightly integrated with the roof and expected to produce about 10000 kWh of electric energy yearly, making this zero emission building a net producer of energy. Although one of the first of its kind in Norway, houses with integrated PV-panels are expected to be common in the future when the market for PV-systems will be customer-driven due to the steady reduction in price for such systems.

There is little doubt that also wind power will be a huge source of renewable electricity by then. Other energy sources such as ocean power (tidal and wave power) will also be present, but to a lesser extent. A breakthrough in hydrogen technology and fuel cells is also possible. Each of these technologies are different regarding the challenges of integrating them, but one of the major purposes of the Smart Grid is that all of them are accommodated efficiently and reliably.

![Image of The Living Lab (ZEB house) at NTNU under construction.](image)

**Figure 2: The Living Lab (ZEB house) at NTNU under construction.**

3.2.3 Examples of challenges and research opportunities

Due to the intermittency of most renewable energy, it is recognized that one important aspect of their integration is energy storage. Norway’s possible role as a green battery for Europe is well known, but will require significant investment in new HVDC-connections to the rest of Europe. Offshore wind power also requires both investments and new developments in HVDC, as does the visionary project DESERTEC (bringing solar electricity on a large scale from Sahara to Europe). For these reasons, it can be argued that novel HVDC-technology is an important aspect of the Smart Grid.
However, solar electricity is first of all a distributed source of electricity. One approach of integrating distributed electricity is by using the concept of a microgrid, where groups of or individual small-scale producers of renewable electricity constitute a more or less autonomous and self-controlled micro system that is connected to the main grid at one point. For the main grid, this then becomes a single point of consumption or production, which reduces the complexity in control from the point of view of the grid. Microgrids will also contain energy storage in the form of either mature technology such as batteries, or developing technologies such as flywheels, superconducting magnetic energy storage, hydrogen and others.

In electricity markets with high penetration of intermittent renewable energy, not only technological innovations are necessary. Mechanisms which enable consumers to respond to changes in electricity supply must also be created. Both regulatory and behavioural aspects must be studied. Advanced metering systems (AMS) will enable consumers to respond to real time price signals, and could be an important instrument to drive such changes.

3.3 Perspective EV integration

3.3.1 Introduction

Norway is by far the country in the world with the largest number of electrical vehicles (EVs) and plug in hybrid electrical vehicles (PHEV) per capita. The EV market penetration per 1000 people was 9.6% in Norway by December 2014 and Norway became the first country where over 1 in every 100 passenger cars on the roads is a plug-in electric vehicle. In total EV car fleet numbers, Norway was ranked number six in the world after USA, Japan, China, Netherlands and France (source: [http://en.wikipedia.org/wiki/Electric_car_use_by_country](http://en.wikipedia.org/wiki/Electric_car_use_by_country)). Good incentives such as tax exempt, free parking, free use of toll roads and bus lanes etc. combined with heavy taxation of fossil driven cars has been important drivers behind this development. By February 2015 the number of EVs in Norway was approx. 48.000 (source: [http://www.gronnbil.no/statistikk/](http://www.gronnbil.no/statistikk/)).

By the end of 2011 it was 2.376.426 cars and 410.730 vans/delivery trucks in Norway. If the average driving distance per year per car/van is 15.000 km electric cars/vans would have used between 5 and 7 TWh per year if ALL the cars/vans in Norway was electric! With an average annual electricity generation in Norway of 139 TWh from March 2011 to March 2013, it is obvious that the energy need of EVs will not be a security of problem especially when considering that it will take decades to replace all fossil driven cars/vans with electric ones.

3.3.2 Challenges

A significant part (ca. 70%) of the LV distribution system is of the type 230 Volt IT system (230 V line voltage) different from the 400 Volt line voltage systems in most of Europe. Thus, a 230V three phase load requires $\sqrt{3}$ higher current to supply the same power compared to a 400V three phase load which in turn give higher voltage drops and losses when supplied by a similar supply system in terms of system strength (similar short circuit impedance.) The strong focus on global warming in the recent years has contributed to a change towards a more climate friendly and energy efficient energy electrical appliances such as EVs, instant water heating systems etc. For many of those including EVs although being energy efficient, they might impose substantial stress on distribution system in terms of voltage quality disturbance and current
overloading. As it has shown that the Norwegian 230 IT system at many supply terminals (i.e. customer connection points) are weak grids compared with the standardized EMC reference impedance, this might give larger voltage quality challenges when connecting EVs, PVs etc. than in many other countries. EV will like DG also change the voltage profile along the power lines and give intermittent power flows which might cause flicker.

3.3.3 Possibilities
EV batteries represent a resource for the distribution grid as well as the installations in terms of energy storage. With Vehicle-to-grid solutions (V2G). V2G could act as an uninterruptible power supply (UPS) for the internal load as well as contribute to demand response services, voltage quality management services etc. The V2G concept has also been addressed from standardisation bodies e.g. ISO 15118 which specifies the communication between Electric Vehicles (EV), including Battery Electric Vehicles and Plug-In Hybrid Electric Vehicles, and the Electric Vehicle Supply Equipment (EVSE). One of the challenges discussed concerning V2G concepts has been how they affect expected battery lifetime.

3.3.4 Relevant research topics
Development, verification and evaluation of smart charging use cases for optimal car owner, house owner and power system efficiency in terms of economy, flexibility, range anxiety, voltage quality, reliability and safety. A subset of this is to study operation and control of EVs (individual or as an aggregate fleet) as well as the interaction between the EVs and the distribution network. is another important topic. Improved EV charging system (smart inverters) with better capabilities for grid support or grid friendly charging and operational flexibility is also a research topic addressing EVs from a Smart Grid perspective. EV mobility can make it difficult to accurately forecast grid loads and ensure proper assignment of charging costs which is an important research topic. Vehicle tracking technologies could improve forecasting and payment but might also raise consumer privacy concerns. EVs integrated with other distributed energy resources like solar PV as an integral part of resilient microgrid systems is also an interesting research area (including aspects such as planning, design, operation, communication, simulation and decision support.)

3.4 Perspective - Buildings

3.4.1 Building design
Buildings should be designed – to the extent that is in the control of the designers – to work in synergy with the grids and not to put additional stress on their functioning. This is especially true for buildings that both produce and consume energy: prosumers. Even though their annual balance may be far from zero-energy or nearly zero-energy (especially for retrofitted buildings), in certain periods prosumers have a net export of electricity to the grid. Similarly, they may have a net export of heat to a thermal grid in certain periods.

3.4.2 Grid interaction indicators
Building designers (architects and engineers) lack indicators that express the synergy between buildings and grids and that can guide them in the design of the buildings’ energy characteristics. Suitable indicators should be defined in cooperation with grid designers/operators, especially micro-grid and thermal grids, and with power market experts in order to reflect both the local and general impact that prosumer buildings may have.
### 3.4.3 Tools and data

In order to estimate the building-grid interaction since the design phase, further development is needed in:

a) Advanced dynamic building simulations tools for the evaluation of different strategies for the control of load, generation and storage;

b) Data on end-users temporal consumption patterns, e.g. for lighting, electrical appliances, cooking, hot water use. Such data should be statistically representative for the type of building in analysis (i.e. residential, office, school, etc.), and eventually standardized and made normative. In the same way as weather data are standardized to provide designers with a reference climate, user profile data may be standardized to offer designers a reference temporal consumption pattern for each type of building.

### 3.4.4 Building operation

For buildings and grids to work in synergy in the operational phase they need to exchange information. Smart grids and smart meters must allow two-ways communication so that, for example:

- The grid can inform the building on day-ahead prices and weather forecasts.
- This information is made easily accessible to the users in the building.
- Buildings can also use the information from the grid to automatically optimise their control of load, generation and storage and communicate back the forecasted import/export of energy for the following day.
- Automatic control of active and reactive power flows is possible, especially for prosumers.

### 3.4.5 Business model

Optimal operational control of load and locally available storage and generation capacity can often better happen at an aggregated level. The aggregation can be at neighbourhood or district dimension, eventually delimited by a micro-grid and/or a district heating system. The delimited area can then be operated as a virtual power plant, exploiting aggregated flexibility in load, storage and generation capacity. The aggregator’s, e.g. ESCO (Energy Service Company), responsibilities and business model need to be developed.

### 3.5 Perspective - Thermal energy

#### 3.5.1 Background

Energy systems in Norway and Europe undergo major changes. Fossil energy resources will gradually be replaced by hydro, wind and solar power and renewable fuels in thermal power and heat. The long-term climate targets in the EU and Norway involves a radical restructuring of the energy system, and new smart grid technologies may play a major role in this development.

The new power generation is mainly intermittent and difficult to forecast, both in the short term (wind) and the seasonal and annual basis (hydroelectric and wind power). Climate change is further expected to enhance the variation in the inflow. This increase variability in supply cause new challenges to power system regulation and stability.
Smart grid technologies, a smart energy system and flexible interaction between the power system and thermal energy (heat) can help to mitigate these challenges. Heat production is large in volume both in Norway and indeed in a European perspective. In an energy system utilizing this smart interaction, heating systems may use electricity when electricity prices are low (high supply situations) and biofuels or other fuels when electricity prices are high (high demand situations). Such flexibility may not only provide both short- and long term flexibility to the energy system, but also add value to renewable energy sources. Also, smart interaction can provide increased security of supply and less volatile energy markets. Flexibility from interactions between thermal systems and the power system is particularly important in regions with a vulnerable power and in regions with high power, much unregulated power generation and limited transmission capacity.

In Norway, the major hydro reservoirs provide considerable flexibility to move production in time (great power flexibility), but over longer periods the production is limited by inflow. As such, hydro power has little energy flexibility. Large inflow variations have therefore been handled by trading with neighbouring countries, where thermal power plants, usually based on fossil fuels, have increased their production in dry years and reduced production in wet years. With the expected reduction in coal power generation capacity, it is necessary to find new sources of energy flexibility, and heat systems may be one source in that regard.

### 3.5.2 Research Challenges

Some of the research challenges related to smart use of thermal energy in the future energy system is listed below. The list is not exhaustive, but covers some key questions:

- How will technological developments in thermal energy affect the possible interaction with the power system?
- What are the likely further development of thermal energy in Norway and Europe, given the current cost and regulatory framework, and the expansion of renewable energy and smart grid technologies?
- How do different solutions for thermal energy contribute to greater stability in the future (smart) energy?
- Does the current policy instruments facilitate an efficient interaction between power and thermal energy?

### 3.6 Perspective - ICT as an integral part of the power grid at all levels

Future grids will be increasingly monitored and controlled by use of ICT solutions in all parts of the power grid, from the producer, via the transmission grid, to the consumer. The objective is to optimize the production in relation to the consumption, improve the efficiency of the network, and increase the awareness of the consumers in terms of his/her power consumption. This opens up a number of opportunities and challenges.
3.6.1 Handling large amounts of data ("big data")

Today, the transmission and regional power grid is relatively well instrumented to monitor the conditions, and to remote control breakers. However, the distribution grid, the low-voltage power grid to the consumer, is rarely instrumented. One expected development of the power grid is an increase in the instrumentation. This enables significant improvements in terms of load prediction, proactive maintenance and fault location of reactive maintenance. In addition, smart meters will be installed at all consumers’ premises. In sum, this lead to a large number of new measuring and control units, which collect large amounts of data that must be aggregated, communicated to the utility companies, and analysed. Pattern recognition for load and variance prediction ("big data") will be a big challenge.

3.6.2 Applications ("Apps") for control and monitoring

Smart meters and massive instrumentation in the distribution grid result in increased opportunities for surveillance and control, provided that the information can be properly protected. This is interesting for the power producers and the power grid companies, but also of potential interest the third party service providers, and for the consumers. Applications using open software solutions, new opportunities with new terminals such as smart phones and tablet (both for operating engineers and consumers), interoperability, the need for new standards, are just some of the challenges that must be addressed.

3.6.3 Effective and flexible communication solutions

Handling of a large number of new sensors, distributed over the grid and at the customers’ premises, requires effective and flexible communication solutions. The Smart Grid will have communication demands with very different usage profiles and requirements. They must be differentiated with respect to the requirements for safety, reliability, throughput (volume) and real-time. In cases where sensors react to events in the grid, the data traffic will be unpredictable, bursty, and locally correlated. Communication protocols to deal with such data swarms are needed. For extremely low latency requirements current technology falls short and tailored solutions are needed.

3.6.4 Cyber security and reliability

Through more instrumentation and ICT the security of supply is expected to be improved in the new power grid with increased variability in usage patterns, small production plants connected the low voltage distribution grid, storage of energy, and with consumers who are both consumers and producers. The infrastructure of the power grid and ICT system will in many cases be physically integrated and co-located. The interaction and interdependence between the two systems is not fully understood, and must be carefully addressed with regard to reliability, performance and information security.

The ICT systems are not perfect, they might suffer from overload, might fail, or have security vulnerabilities. It is therefore essential to understand the interaction between power grids and ICT systems, and how the overall system reliability and the resulting security are affected. How should we deal with effects due to interactions between ICT and power system? How can we avoid the cascading effects due to unpredictable/unexpected dependencies (hard to predicted due to the total complexity, and because the cooperating systems are designed in different traditions/requirements).
Protection of privacy has received much attention in relation with the introduction of smart meters. It is important this is handled in a proper way, but it is critical that other aspect of "cyber security" is given equal attention. If it opens for information sharing and possible remote controls, or information access for a third party service provider, it is important to prevent unauthorized access. Moreover, it is very important for companies that operate the future power grid is familiar with, and has good procedures to deal with, the new threats imposed by the integration of ICT systems and power grids.

3.7 Perspective - Business opportunities, new markets and services

3.7.1 The need for incentives

As introduced in section 2.2, the Smart Grid may provide a wide range of benefits for the energy systems, the energy markets and for the actors in the value chain, spanning from cost savings, via increased market efficiency to reduced environmental impacts, just to mention a few. One source to such benefits is the increased operational flexibility at demand side that the Smart Grid technologies may represent. Such flexibility may stem from demand response options (cutting or moving demand), utilizing energy storages, switching between primary energy carriers or dispatching distributed generation.
However, in order to motivate companies and private persons to invest in such equipment and to operate new and existing technology in new ways, incentives are needed. Current regimes do not provide strong incentives, for instance since end-users in the electricity market are not exposed to the time varying wholesale market prices, or the grid tariffs do not provide strong incentives to change consumption pattern.

3.7.2 New market design, new business models and new market roles
In order to stimulate end-users to more actively participate in flexibility activities, and hence achieve increased benefits, changes in the market regime must be developed. One obvious way to go is to introduce more dynamic pricing regimes, like hourly settlement in the end-user market or time varying grid tariff pricing. Another option is introduction of new market roles, like aggregators that collect flexibility and sell it in the market on behalf of the underlying end-users. Such activities will on one side increase market volumes and on the other side open new markets for the end-users.

Such changes will require new contract types and new business models that regulate the rights and obligations for each party and distribute profits and risks in efficient ways.

3.7.3 New services
New and more dynamic technology in the energy systems and stronger incentives through more dynamic pricing or other arrangements will require new ways of operation. The end-user themselves are not anticipated to be very active in switching on or off equipment. A more viable approach is that software will handle such operations or that new market roles like energy service companies (ESCo) or aggregators will provide attractive products and services to the prosumers and the market. Combinations of new business models, bundling of products and services related to energy and other areas like health, security or entertainment and trading of aggregated volumes of flexibility are examples of how added value can be created for the prosumers and companies in the SmartGrid market.

The starting point in Smart Grid is deployment of a wide range of new technologies for energy generation, storage and consumption and technologies for metering, supervision and control of these, including needed infrastructure. Delivery and maintenance of such technologies opens for new business opportunities for technology vendors. In addition, as described above, there is a need for new products and services to operate the equipment in optimal ways depending on market regimes and market conditions. Business opportunities will be opened for companies with innovative and attractive offerings of products and services.

3.8 Perspectives Smart grids for Smart Cities

3.8.1 Background
Cities are complex socio-technical systems that are based on multiple interactions between individuals, markets, technologies, infrastructures, networks, policies and public services. This implies that energy can no longer be addressed as a standalone area. A more holistic approach is required to take into account both shifts in how people live and industry uses energy, but also of the fast pace of technological change. Integration of energy systems can contribute substantially. An intelligent development of smart cities
therefore needs to be embedded in local socio-economic and political structures and processes as well as technology deployment. A smart city uses digital technologies in all areas of the economy, resulting in efficiency, lower energy usage and related emissions and lower overhead costs for companies, the public sector and individuals.

### 3.8.2 Research Challenges and Opportunities.

With an almost emission free energy sector, delivery of further CO2 reductions to achieve Norway’s energy and climate targets requires smart energy system in cities - complex environments integrating electricity, transport, gas, heating and cooling and user/prosumer behaviour in a future-proof way. The increasing share of variable renewables and coupling of various energy systems with significantly different reaction times will require innovative forecast methods of energy demand and production. Research challenges include integrating local energy storage capacity and develop a complete solution to updating ageing infrastructures to meet new demand patterns.

In a Smart City environment, monitoring energy infrastructures creates large amounts of data, which lead to data overflow problems and communication- and archiving challenges. Smart meters also have to be engaged in data processing, which creates a need for research in data analytics, machine learning and predictive analytics. Security and privacy-preservation schemes must be designed to guarantee anonymous data processing.

The change from end-consumer to prosumer and the increase in the number of prosumers creates opportunities for smart end-users and services innovation. Public awareness, the circumstances of such innovations, how they take place and which of the solutions are actually used by consumers and prosumers are unknown and need to be researched. Innovative information visualization and user interface is considered vital to support user decisions.

Implementing efficient business models in digital and decentralized energy systems is challenging. Value will be created in yet unknown parts of the value chain and by new actors, however, there is great potential to deliver solutions that can be relevant and transferrable within Norway, throughout Europe and globally.

### 3.9 Perspectives - Non-technical aspects of smart grid development in Norway: Standardization, third party actors, new market models, end-use and user acceptance.

When the Water and Energy Directorate put Automated Metering Infrastructure (AMI) on the agenda for the Norwegian power grid in 2007, and set the deadline for 2017 (postponed to 2019), work has been ongoing in Norwegian network companies to map out and define what it means to construct the Norwegian smart grid.

Smart meters have implications for the entire energy system. The actors of the energy network are many and diverse, and rationales for implementations vary in accordance, and the stakes are high. How agendas for the energy network of the future vary, overlap and create controversies between the actors and their fundamental societal values is an area of activity which requires holistic analyses across technology and economy. On a macro level, hopes are that new information about load and consumption patterns will
enable grid companies to become more efficient, both in day to day operations and when planning investments. Also, the market is expected to have a transformation potential, e.g. value chains between the different actors in the power market will become seamless as information is flowing freely. New business models may also follow, especially at the side of the end-user, where new kinds of technologies, both software and hardware, could provide new means of relating to energy consumption as consumers may become more active and more responsible actors in the power market.

In this sense, the development of smart grids can result in a fundamental restructuring of how society as a whole relates to production, transmission and consumption of electricity. However, even if only parts of the existing plans are realized, the societal implications are considerable. Following this, it is critical that research is focused on how smart grid technologies may contribute to change and in which ways they best can benefit society as a whole.

3.9.1 Third party actors, suppliers and other market actors

The markets for third party actors for instance software companies selling communication technologies related to smart metering, is so far largely theoretical. As the regulatory work is still in the process of asserting itself in a practical sense, third party actors have to a large degree remained passive in the face of great uncertainties. To map out possibilities of application and how to make use of them it is important to analyse third party actors’ roles and mounting influence on the shaping of the future grid. The fact that grid companies and government alike have made clear that they will leave it up to market to exploit the possibilities of AMI beyond the regulatory demands, adds strongly to the research relevance of the activities of these actors, as they frame implicit users within their technological designs.

3.9.2 Public acceptance and end-use

Implementing a new technological infrastructure, like smart grids, will potentially give rise to concerns in the population, as some examples have already shown. A successful implementation of smart grids will rely on public acceptance. For this reason it becomes important to study attitudes towards smart grid technologies and map out potential controversies on an aggregated level, including policy and industry strategies for including users and instilling positive engagements. In this way social science perspectives can provide means of making technology development processes more democratic and including, thus creating solutions which include the terms of future users.

One of the most important actors in the energy system is indeed the end user. But not only is the end user a central part of the energy chain, the grid is also an inseparable part of everyday life in modern society. The end user exists in an intersection between regulation and technology development. To understand how the user consumes energy in a broader everyday setting is essential for our ability to develop smart grid solutions which have the necessary change potential for consumption patterns. If the technology ends up getting stowed away in a drawer, it obviously lacks such potential. The so called technology centred “design-and-adopt” approach is still dominant. However, there is a need for a larger focus on the users of the technology (the households) and integrated design of:

- Technologies in households
- Electricity consuming everyday practices in households
- Electricity system and administrative/regulatory rules
• Public acceptance of smart grids

This kind of research focus will be able to provide knowledge about how to enable users to implement and fully exploit the potential of smart grid technologies. Interdisciplinary knowledge about technology policy dimensions will also be necessary for developing and implementing smart grid technology. This entails that research and development is focused on expanding such topics as:

• Innovation, design and standardization: How is the knowledge base constructed, and what is the potential for commercial application?
• Infrastructure: What physical demands will frame the possibilities?
• Efficient regulation: What prerequisites exist to the standardization of technology, and what is the knowledge base for handling risks?
• Democratic dialogue: How can the technology be understood, translated and put to use?

3.10 Perspective - Control and monitoring

Control and monitoring are important functions in the operation of electrical power networks. In the process of converting the power grid to a Smart Grid, these technologies must be expected to find even more widespread application.

3.10.1 Transmission networks

Traditional ‘state estimation’ in transmission networks has only provided steady state estimates, due to problems with synchronizing measurements in time (relative to a grid frequency of 50 or 60 Hz), when the measurements are taken at locations that are far apart. Novel Phasor Measurement Units (PMUs) have access to a very precise clock signal from GPS satellites. This enables dynamic state estimation that can uncover oscillations distributed over large geographical areas, and thereby also enables active control to stabilize such oscillations. Note that such estimation and control applications will be highly dependent on data communication, making it necessary to consider both the communication reliability and time delay in their design.

3.10.2 High Voltage DC networks

HVDC cables are used for transferring large amounts of power over long distances. Traditionally this has involved individual cables linking two points. However, HVDC networks are foreseen, for example connecting the countries around the North Sea, as well as oil platforms and offshore wind farms. Due to very fast dynamics, reliability and communication issues, a centralized control solution for such networks is not desirable – instead local control at each terminal is preferred. Ensuring performance and fault tolerance in such a system is a challenge to control.

3.10.3 Power distribution: microgrids, distributed generation and demand response

In conventional power networks power flows from a moderate number of large generators to a large number of consumers. In the future, much more distributed power generation based on renewables is expected ‘far out’ in the distribution grid. Consequently, power flow may change direction, and it is
necessary to ensure that fault detection and protective equipment will be able to handle such reversals in power flow.

Due to high demand and/or grid faults, a situation may occur where a geographical area cannot be supplied with sufficient electrical power from other areas or from centralized generation. In such cases, one must maximize the utilization of local power generation, and also adjust local consumption to the power available. This needs to be done in an economically sound way, reflecting individual customers’ willingness to pay and quality-of-service requirements, and with minimal effects on critical areas of society. This can be viewed as a large scale distributed and hierarchical optimization problem, clearly with strict stability demands, non-linear cost functions and complex constraints.

3.10.4 Power electronics

Power electronics are key components in the Smart Grid in ensuring the compatibility of the characteristics of the power supplies, the characteristics of the network, and the characteristics of the load. Power electronics are already found in numerous applications in power systems, from local motor controls to converters in HVDC terminals. These power electronics depend on their own embedded control functions – which often have to be very fast. New control applications and steadily increasing performance requirements increases the demands on the embedded controls, and the design of these control functions also need to consider the computational hardware on which the control is implemented. These issues are further complicated by the fact that the final control elements in power electronics are often switch settings, which by their nature is discrete-valued (on/off). Often, they are represented using continuous-valued approximations based on averaging and pulse-width modulation. However, to truly maximize performance the discrete nature of the switches will need to be addressed – which typically results in computationally very challenging control problems.

3.10.5 Research requirements for monitoring and control in Smart Grids

Although the brief description above by no means give a complete picture of the challenges faced by monitoring and control systems in the Smart Grid, it is hopefully makes it clear that to develop a Smart Grid a lot of applied research in control and monitoring will be required.

In addition, the description above points to several areas for generic control research:

- Distributed and hierarchical control and estimation
- Control design accounting for communication quality – or control and communication co-design.
- Efficient formulations for control problems described by discrete variables
- Embedded control implementation
3.11 Perspective - Standardisation

3.11.1 The role of standardisation in Smart Grids and Smart Metering

The main role of standardisation broadly speaking is to establish a standardised view and a set of terminology to describe the Smart Grid and to facilities economic and secure operation of the Smart Grid. The standardisation mandate 490 from EU to the European Standardisation Organisations CEN (ISO), CENELEC (IEC) and ETSI (ITU) illustrates the expectations to standardisation:

«The objective of this mandate is to develop or update a set of consistent standards within a common European framework that integrating a variety of digital computing and communication technologies and electrical architectures, and associated processes and services, that will achieve interoperability and will enable or facilitate the implementation in Europe of the different high level Smart Grid services and functionalities as defined by the Smart Grid Task Force that will be flexible enough to accommodate future developments. Building, Industry, Appliances and Home automation are out of the scope of this mandate; however, their interfaces with the Smart Grid and related services have to be treated under this mandate.»

Some key words are highlighted above as they exemplify the areas where a good knowledge base has to be developed to achieve the overall visions for the Smart Grid. It should be noted that a large number of international standards relevant for Smart Grids are already identified http://www.iec.ch/smartgrid/standards/ .

3.11.2 Architecture and use cases

A main challenge in describing and managing a complex system of systems which the Smart Grid definitely is, is to structure the Smart Grid Domain and to split it into smaller parts to make it manageable. To develop architectures and high level use cases have been the trend so far and are expected to continue. To develop at a holistic and consistent description is especially demanding a the Smart Grid is so broad in its content, but is need to describe functionalities and interfaces both from the electrical energy and power perspective and the information and communication perspective. High level use cases are to be standardised to help stakeholders to identify functionalities which might provide benefits as well as serve as a platform to identify interoperability and security issues.

3.11.3 Standardisation and research

Standardisation is not a technical research issue in itself, but can be regarded as a consensus arena open for all stakeholders meeting to develop standards which cover a market need. Stakeholders' often conflicting interests needs to be balanced both from a technical and economic perspective and this balancing arena calls for well documented scientific and practical knowledge from a large number of domains (transmission and distribution grid, markets, power generation, end users, smart houses, communication, IT etc.)

7 The corresponding worldwide standardisation organisations are given in parenthesis.
4 An overview of Smart Grid R&D in Norway

This chapter provides a brief overview of Research and Development (R&D) in the Smart Grid area in Norwegian universities, colleges and research institutions. In addition, European R&D in the area with particular relevance to Norway is also briefly described.

Although the need for more renewable production, and the introduction of such renewable production in the grid, is one of the main drivers for much of the foreseen Smart Grid research, this overview will not attempt to cover research in the renewable energy production technologies, but only cover research relevant to the introduction of such production in the grid.

Furthermore, no attempt is made at providing a comprehensive presentation of Smart Grid research in companies. This is due both to the need for secrecy regarding commercial plans, and the fact that major suppliers in Norway have the bulk of their research in other countries.

4.1 Demonstration projects

Six demonstration projects have been established, providing platforms for demonstration of different aspects of smart grid technology.

4.1.1 Demo Steinkjer

This demonstration project enables the testing of advanced meters, system services and other products on a selection of 770 end users, including households, business customers and industrial companies. The main focus of the demonstration project is the development of commercial products and services for the smart grid of the future as well as study how the new products and services can enhance power system efficiency.

4.1.2 Smart Energi Hvaler

This demonstration project covers all the 6800 grid customers in the Hvaler municipality. The focus of this demo project is the use of smart meters and technologies supporting grid operation as well as to provide incentives for consumer and market innovations.

4.1.3 Demo Lyse

The focus of Demo Lyse is ICT infrastructure and architecture. In addition to installing smart meters at the customer sites, additional communication capacity will be installed, and an easy-to-use information portal and user interface provided. The information portal will not only provide a communication channel between the network operator and the customer, but the integration of supplementary services will also be addressed, with welfare technology being an area of particular interest.

4.1.4 Pilot Northern Norway (TSO)

This project is testing smart solutions for the transmission system operator (TSO). The new models and tools for planning and operation are connected to and demonstrated at the regional control centre in Alta (RCC Alta), however the geographical are involved is Finnmark, Troms and the northern part of Nordland county. The pilot has a focus on: Better monitoring, prognosis and control of energy use at the customer
side – among others testing TSO/DSO/customer interaction to utilize flexibility for demands response
concepts to enhance system reliability. Improved control of vulnerability in operation with smarter
measurement and tools for decision making. Smart management of renewable energy resources when
massive amounts of renewables are going to be integrated into the transmission system. Smarter operation
when there is a sharp increase in the number of electrical vehicles. The aim is to reduce costs of operation,
increase balancing reserves, and predict and handle imbalances with a much higher degree of efficiency.

4.1.5 Demo Skarpnes (plus houses and "prosumers")
The demo is investigating the impact on the local grid of a residential area consisting of plus (zero) houses
in southern Norway. 19 detached houses, 20 apartments and 8 semi-detached houses. All the buildings are
equipped with PV panels, CSP and energy wells, and they are self supplied with energy over the timespan of
a year. For the grid company it is of particular interest to monitor and analyse the variation in need for
power of the single and the aggregation of buildings during different seasons, and also to understand
better the energy use of the customers with regard to different energy intensive appliances, EVs, heating,
lightening and so forth.

4.1.6 Demo Bergen
The demo focuses on the next generation of smart substation as well as solutions for remote control and
automation in the distribution system. More than 20 distribution substations will be equipped with new
sensors and monitoring solutions (RTUs) and selected locations in the distribution system will be equipped
with switches to increase ability to monitor and control remotely. The smart components will be integrated
with DMS (Distribution Management Systems). Various alternatives for communication (e.g. fibre and
radio) will be studied. The main objectives are better grid utilization and improved reliability by increased
availability and utilization of real-time data, improved fact-based decision making (both for investments
and operations) and improved understanding of impact on the grid when integrating more EVs, prosumers,
industrial customers with large rectifiers/inverters etc.

4.1.7 National Smart Grid Laboratory & Demonstration Platform
The National Smart Grid Laboratory & Demonstration Platform is hosted by NTNU and is a joint SmartGrid
and Renewable Energy Laboratory of NTNU and SINTEF which also includes remote access for other
research and industrial partners. The laboratory is a complete physical model of a power system including
transmission and distribution systems, power generation, network users (loads, smart house, prosumers...)
and the necessary ICT infrastructure. The concept is shown in the figure below:
Figure 4: NTNU laboratory Concept.

The system is designed as a flexible infrastructure where passive electrical components, electrical machines and power electronic converters up to the 70 kVA power range, with associated control and protection systems, can be tested under controlled conditions. The infrastructure is suitable for testing of individual components or conversion units, as well as studies of ac and dc power systems with multiple machines and converters in a wide and flexible range of configurations.

The high power rating allows for accurate downscaled testing of high power equipment. Most of the equipment is developed in-house, giving high controllability. Previous research focused on wind grid integration & control aspects, including HVDC and Hardware-in-the-Loop. Near-future lab extensions include smart grid functions, e.g. different short-circuit emulators and energy storage. Construction completion is expected by 2018.

The user is free to choose the physical setup of sources, loads and connecting line equivalents as far as they can be connected. For the Hardware-in-the-Loop, the user can supply any grid model to be emulated in a Simulink format for the OPAL-RT.
4.2 Norwegian research providers

4.2.1 Narvik University College
Research on distributed generation, connecting distributed energy resources to the mains grid by means of power electronics and advanced control structures. Research on microgrid topologies and operation.

Main projects:

- NOSEG project – Nordic Smart Energy Simulation Group. Research on wind power and smartgrids. Partners: Yrkeshögskolan Novia, Umeå University, Vaasa University, Vaasa yrkeshögskola, Tampereen teknillinen yliopisto, Narvik University College

4.2.2 University of Stavanger
UiS currently participates in the SEEDS research project (funded by the EU - 7th framework program). The goal of SEEDS is to develop an open architecture and system for adaptive real-time energy management for buildings, surrounding areas and open spaces that integrate optimization and self-learning methods, advances in wireless sensor technology and building technologies to optimize a building's performance in terms of comfort, energy efficiency, resource efficiency, economic return, functionality and lifecycle value.

Part of the UiS campus has been used as a pilot to validate SEEDS project. Another pilot is an office building plus parking area situated in Madrid (Spain). In both pilots, wireless networks of sensors and actuators that were specially developed for SEEDS were implemented as well as the necessary ICT infrastructure.

UiS is also participating in the prototype of Lyse smart homes under the Safer@home project. The University of Stavanger hosts the Centre for IP-based Service Innovation lab (CIPSI) that is connected through fibre optic to the smart home prototypes from Lyse. UiS is providing a big data infrastructure to Lyse and developing a distributed big-data analytic engine. The big-data engine is used for the optimization of smart grid energy consumption and to enable safer living with preventive care through the use of non-invasive technology. This research is funded by the Research Council of Norway.

Finally, UiS is participating in the Triangulum project, where the city of Stavanger was recognised as one of the nine lighthouse cities in the EU’s Horizon 2020 Smart Cities and Communities programme. In this context, partners work closely together to demonstrate new integrated solutions between energy, ICT and mobility to significantly reduce energy consumption.

4.2.3 Norwegian University of Life Sciences
Smart grid activities at Norwegian University of Life Sciences focus on the following two main issues:

1. Economic, market and system impacts of demand side management/improved flexibility in electricity consumption
2. Market and system studies of integration of renewable energy in the future energy system

Regarding 1) – “Demand side management” – UMB have attended the ERA-Net project “Improsume” led by NCE Smart Energy Market in Halden. In addition, we have two PhD projects on this topic, of which one is an industrial PhD employed by Brady Energy.
Regarding 2) – “Integration of renewable energy” - the project Flexelterm, financed by the Norwegian Research Council and the major energy companies in Norway focuses on opportunities for smarter and more flexible interaction between the electricity system and thermal energy. The industrial PhD project “utilization of consumer flexibility and distributed generation for balancing the power system with Enfo Energy were started in November 2013. In addition, there are two more PhD projects focusing on economic and market impacts of integration of renewable energy in the Nordic energy system.

In addition to the projects specified there are a number of smaller activities and projects related to smart grid and the future smart energy system.

### 4.2.4 Norwegian University of Technology and Science

The faculty for Information Technology, Mathematics and Electrical Engineering (IME) is responsible for the smart grid activities related to computer science / information technologies, mathematics, electronics, communication technology, engineering cybernetics and electric power engineering. IME/NTNU took together with SINTEF Energy in 2010 the initiative to creation of a national smart grid centre. IME made the smart grid initiative to a strategic activity at the faculty by making it to one of the Lighthouses at the faculty. A Lighthouse is special strategic project where the faculty allocates resources for administration as research activities. After this was created in 2010, in total 12 PhD/Post.Doc positions were allocated to the activities which are equivalent to 25 mill. NOK as strategic funding. Other faculties at NTNU have significant activities within the smart grid as well (Faculty of Humanities – HF, Faculty of Social Sciences and Technology Management – SVT, The Faculty of Natural Sciences and Technology – NT).

#### 4.2.4.1 Department of Electrical Power Engineering (IME)

**Background**

The department covers all the topics and activities related to conversion, transportation and distribution of electric energy to the end users. These represent the fundamental infrastructure in a Smart grid. Most of the activities at the department are therefore related to the smart grid concept as the individual components constitute a system which is supposed to be used in an efficient way. The grid related focus will be to use the individual components in a secure way to avoid degrading and possibly sudden breakdown. From a system perspective the operation must be as flexible as possible to preserve the balance between the supply and demand. To achieve this, some important activities are:

- Accurate modelling of components, limitations and diagnostics
- Develop new components and control strategies of these
- Monitor both component and system limitations by using sensors, simulations and advanced decision support algorithms
- Develop robust protection schemes for fault isolation
- Quick restoration by using backup schemes, network topology changes, distributed generation of end-user flexibility
- Develop advanced methods for security assessment and control

Most of the research and teaching activities at the department are related to modelling, testing, system analysis and planning,
Status and future activities

An important resource for the research activities are the PhD- and the MSc-students. PhD-projects are either based on strategic funding from NTNU or are a part of research projects funded through the Norwegian Research Council. MSc-projects are either defined in collaboration with the industry or defined by the professors and an element of “curiosity research” as a longer term strategy to identify new promising areas.

Major strategic areas at the department are:

- The Norwegian Centre for Hydro Power
- Offshore wind and grid
- Smartgrid
- Industrial applications of power electronics

All these areas have relevance for the National Smartgrid Research Centre. A new national research laboratory funded by the Norwegian Research Council are under development in the premises of IME.

4.2.4.2 Department of Interdisciplinary Studies of Culture (HF)

Smart grid activities at the department of interdisciplinary studies of culture largely focus on the role of households and technology users in smart grid developments. On one hand, this means that we do hands on studies of how users interact with new technology, and how smart grid demo projects works to integrate households in their activities. This focus on users also allows us to look into issues like public acceptance, engagement and resistance towards smart grid technologies.

We also study policy and regulation processes, with a particular focus on how knowledge from different scholarly disciplines such as economics and engineering shape outcomes. We are also interested in standards, possibilities or barriers to innovation and the study of socio-technical development trajectories.

Many of the other technologies studied at the department are also highly relevant in a smart grid perspective, such as studies of electrical vehicles, various types of renewable energy technologies, energy policy studies etc.

4.2.4.3 Department of Industrial Economics and Technology Management (SVT)

Smart grid activities at the department of interdisciplinary studies of culture largely focus on the role of households and technology users in smart grid developments. On one hand, this means that we do hands on studies of how users interact with new technology, and how smart grid demo projects works to integrate households in their activities. This focus on users also allows us to look into issues like public acceptance, engagement and resistance towards smart grid technologies.

We also study policy and regulation processes, with a particular focus on how knowledge from different scholarly disciplines such as economics and engineering shape outcomes. We are also interested in standards, possibilities or barriers to innovation and the study of socio-technical development trajectories.
Many of the other technologies studied at the department are also highly relevant in a smart grid perspective, such as studies of electrical vehicles, various types of renewable energy technologies, energy policy studies etc.

4.2.4.4 Department of Engineering Cybernetics (IME)

At the Department of Cybernetics, research activities involving Smart Grid are integrated in the following areas:

**Power balancing and control of multi-terminal HVDC:** both applying a Model Predictive Control (MPC) approach. This research is funded by the Research Council of Norway, industry support, as well as funding from the IME faculty of NTNU (I think there is 2 PhDs associated with this project with Morten Hovd as supervisor). The stability of offshore DC grids is a research task in this area and the focus is on the impact of control and on control interactions among the different components of the DC grid. Stability analysis methods and tools are currently being investigated. A PhD student (Amin) is allocated to this task and the work is ongoing in collaboration with the Department of Electric Power Engineering within the NFR KPN project *ProOfGrid*.

**Ship Power Management:** this area focuses on the integration of smart grid technology in marine vessels power plant to reduce the loss of power units. Smart Grid systems are used for controlling components such as redundant bus-tie breakers and transmission lines to prevent loss of power when one or multiple failures occur. Smart-grid solutions should use priorities to maintain power distribution to critical systems. Such critical systems could be the navigation system (including DP systems and thrusters), generator cooling systems and fire-fighting systems. Ship power management has clear parallels to demand response in microgrids.

**Controllers design for Renewable Energy Systems:** this area covers the design of control systems for various scenarios of renewable energy applications. Some of the areas in which activities are already ongoing are listed below:

**Microgrid:** this area focuses on stand-alone power system solutions with several types of sources (Solar PV, Hybrid PV-Thermal, Wave Energy, and hybrid wind –solar–diesel). Microgrids demand functionalities and solutions that are in the realm of the Smart Grid. Real time power balancing and overall management of the microgrid requires advance control of each component and of the entire system as well as demand response features. A specific focus in this area is the role of control design (architecture, properties) in the stability of the microgrid. Stability analysis methods and tools are currently being designed for application in diverse microgrid cases. Currently 3 PhD students are allocated to this topic.

**Hybrid Solar PV-Thermal systems:** this area focuses on the optimal extraction of electricity and heat from PV solar panels. This solution can be part of a home microgrid system or of stand-alone systems for remote areas. This activity runs in collaboration with the EPT Department, the Department of Electric Power Engineering and 3 African Universities.

**Electric Vehicle Integration:** This area focuses on the aspects related to software engineering that will be required for an effective integration of electric vehicles into the Norwegian distribution systems. Currently,
there is one PhD student allocated to this task in close collaboration and co-supervision with the Departments of Electric Power Engineering and Computer Science.

The department also participates in the ARTEMIS eGotham project that develops an open architecture and embedded infrastructure for microgrids. The research focus is on the communication part of the infrastructure. One postdoc is associated with the project.

In addition, many of the other technologies that the department works with are relevant for the Smart Grid, ranging from state estimation and fault detection to embedded computing systems and human-machine interaction.

4.2.4.5 Department of Telematics (IME)

The research activity at the department covers security, dependability and system management architecture. Although the department's expertise is broad in the field of information security, the currently focus is on incident management in DSOs, and in particular how to prepare for the new set of threats that the DSOs will experience due to high integration if ICT in all levels of the power grid. Such integration of ICT is partly motivated to improve the operation. However, the ICT system in itself might be a threat to the operation of the power grid. The change in the overall dependability of the power grid with ICT integration, is not understood. Ongoing research at our department addresses this issue by building models to capture the complex interaction and interdependencies. Finally, the department is involved in defining management architecture for Smart homes such that either the household can control its consumption, or leave this (partly) to its DSO.

The department participates in the project "Next generation control centre" together with the Department of electrical power engineering and Department of computer and information science. The objective is to develop methodologies to support the operation of the future power grids. There are two PhD and two professors associated with the project.

In addition to the aforementioned expertise in information security, dependability and performance, the department has broad competence in communication technology and system and service development methodology for communicating systems.

4.2.4.6 Department of Electronics and Telecommunication (IME)

The research activities are focused on sensing and communication of the SmartGrid. Modelling the local grid measurements for the purpose of compression, transmission and estimation. This work enables remote monitoring of the grid at the lowest level, e.g. for harmonic detection and compensation. It also enables analysis of the information flows generated by grid measurements to evaluate communication system behaviour and requirements to support the measurement traffic.

A communication system supporting a SmartGrid can use current state of the art communication technology to solve most conceivable requirements, with a few notable exceptions. Whenever the traffic requires extremely low latency, current technology, especially for distances found in distribution networks, falls short. Similarly, if monitoring sensors react to a common event in the network, simultaneous traffic occurs, and networks easily become congested if they are not designed to handle the sensors as a group. Similar problems occur in current mobile networks under the name of "signalling storms". 
As a summary, the department works with SmartGrid communications and signal processing with focus on two areas:

- low latency measurement communication methods for extremely low latency, and
- communication system analysis and protocols for supporting correlated measurement traffic.

4.2.4.7 Department of Computer and Information Science (IME)

One of our main activities is centred around the “Next generation Control Centres” project which is funded collaboratively by NTNU and Norwegian utilities. One of the focuses in the project is to develop computational methods for load prediction using power load time series data to predict the expected load in the next 24 hours. The second problem in focus is to analyse the smart meter data to anticipate the source of energy consumption, e.g., whether the residence that the smart meter data belong to has an e-car.

The department of computer science has expertise in intelligent user interfaces and is planning to deal with user interfaces that meet special needs in Smart Grid.

The department does research also on agent-based methods and multi-agent system architectures which is rather relevant for Smartgrid because of its distributed nature which will be more dynamic with new types of production (e.g., solar cells) and consumption (e.g., e-cars) sources which can be modelled as agents.

4.2.5 NCE Smart Energy Markets

NCE (Norwegian Centre of Expertise) Smart Energy Markets is one of 12 Norwegian expertise centres with the objective to create industrial development and growth through competence development and cooperation between companies and academia. NCE Smart’s main focus area is at the intersection between end-user flexibility, market design/business models and ICT systems. NCE Smart has centre management in Halden, but partners nationally and internationally.

In 2013 NCE Smart is involved in the following R&D projects:

- Manage smart in SmartGrids
- IMPROSUME
- DeVID
- Global challenges and local solutions

4.2.6 SINTEF Energy Research

SINTEF Energy Research with core expertise related to power production and conversion, transmission/distribution and the end use of electrical energy, carries out Smart Grid technical and system oriented research in most Smart grid domains where power engineering expertise is required.

SINTEF Energy Research is the Norwegian partner in the European Energy Research Alliance (EERA) Joint Programme on Smart Grids which is a collaborative platform for Smart Grid Research within the following areas.
• Network Operation
• Energy Management
• Control System Interoperability
• Electrical Storage Technologies
• Transmission Networks

SINTEF Energy Research is participating and leading a number of national and international Smart Grid R&D projects. The most important ones (2013) are listed below:

• GRID+ - Supporting the Development of the European Electricity Grid Initiative (EEGI)
• DeVID – Demonstration and verification of intelligent distribution grids
• Spesnett: Voltage quality in Smart Grids
• EcoGrid EU - A Prototype for European Smart Grids
• Optimal infrastructure for seamless integration of distributed generation (OiDG)
• Smart regions - Promoting Best Practices of Innovative Smart Metering Services to European Regions
• Next generation control centres for Smart Grids

SINTEF Energy Research and NTNU Department of Electrical Power Engineering are hosting a Smart grid laboratory. The laboratory with its high power rating of 150 kVA and its wide range of network components is well suited for modelling both transmission and distribution voltage networks with a variety of different generators. The lab includes equipment to emulate distribution and transmission networks as well as energy storage technologies.

4.2.7 SINTEF ICT

The smart grid activity at SINTEF ICT is focused on our activities in the research project we are participating in, both national and international. Demonstrators in real environments are important for us, and we put large effort in this. Our focus areas are:

• Information exchange infrastructure, especially focused on open solutions
• Power balancing (demand – response)
• Optimal power flow
• Analysis with respect to security in the grid
• Interoperability between different standards
• System design to maintain flexibility with respect to being able to replace current technology with future solutions
• Solutions for to better interact with the marked (forecasting of consumption, control algorithms and technologies needed for supporting new tariffs and aggregator functionality)
• Sketching complete systems enabling the end-user to take the smart grid technology in use on their own premises.

We also have some activity regarding modelling of building with respect to thermal storage and by that being able to move energy consumption in time.
At the end of 2014 we are involved in several international and national smart grid projects and activities, the most important are:

- E-GOTHAM: Sustainable-Smart Grid Open System for the Aggregated Control, Monitoring and Management of Energy (ARTEMIS)
- I3RES: ICT-based Intelligent management of Integrated RES for the smart grid optimal operation (FP7)
- AFTER – A Framework for electrical power systems vulnerability identification, defense and Restoration (FP7)
- DeVID – Demonstration and verification of intelligent distribution grids (national)
5 European Smart Grid R&D

The main aim of this chapter is to briefly describe European Smart Grid R&D with relevance for Norway, both from an application (e.g. of interest for Norwegians DSOs) point of view and from a Smart Grid industry point of view. Several relevant European R&D projects are already mentioned in the different chapters from the Norwegian Research Providers. These European projects should of course be of special relevance for Norway, but they will not be further addressed in this chapter.

The European R&D projects are numerous and as a consequence various European institutions have created Smart Grid Project Catalogues and Smart Grid Project Labelling Procedures to support Smart Grid stakeholders in navigating and in the jungle of projects. The most important are:

- The Smart Grids Projects Portal, a joint initiative by European electricity association EURELECTRIC and the European Commission's Joint Research Centre (EC JRC) - [https://portal.smartgridsprojects.eu/Pages/default.aspx](https://portal.smartgridsprojects.eu/Pages/default.aspx)
- The GridInnovation-on-line searchable database developed in the framework of the FP7 GRID+ project - [http://www.gridinnovation-on-line.eu/](http://www.gridinnovation-on-line.eu/)

The 2012 JRC Smart Grid project inventory includes 281 smart grid projects and 90 smart metering pilots and roll-outs. The catalogues and database are not complete as their input depends largely on questionnaires whose distribution and response rate have been less than 100%.

The European Electricity Grid Initiative (EEGI) proposes a nine year European research, development and demonstration programme initiated by grid operators to develop a Smart Grid for Europe by 2030 and is a part of the SET-Plan (European Strategic Energy Technology Plan). The EEGI is driven by grid operators and have a short/medium term horizon.

EEGI has as mentioned a labelling procedure to help stakeholders to identify the most important projects. The system is illustrated in Figure 5.

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8 JRC (European Commission’s Joint Research Centre - Institute for Energy and Transport) is the European Commission’s in-house science services which perform independent scientific research and support EU policy-making on transformations towards smarter and interoperable electricity systems.
Projects that might qualify for EEGI labelling as ‘core projects’ (with budgets of over € 15 million) represent 14 % of the total (around 40 projects) and 66 % of the total budget in the JRC catalogue (€ 1 200 million);

Projects that might qualify for EEGI labelling as ‘support projects’ (with budgets of between € 2 million and € 15 million) represent 35 % of all projects (around 100) and 29 % of the total budget (around € 530 million);

The great majority (80 %) of the budget is allocated to functional areas at the distribution level. The great majority of projects in the transmission clusters are ‘support projects’.

In the JRC catalogue the projects are classified depending on their applications according to the following list:

- Smart Network Management
- Integration of DER
- Integration of large scale RES
- Aggregation (Demand Response, VPP)
- Smart Customer and Smart Home
- Electric Vehicles and Vehicle2Grid applications
- Smart Metering
- Other (e.g. communication infrastructure, storage)
On a high level all these applications areas are of Norwegian interest and relevance. However, to identify those most relevant, the projects have to be studied in more detail so that their characteristics match Norwegian grid, generation and electricity use characteristics.

The more long term Smart grid R&D is expected to be driven by EERA (European Energy Research Alliance) which has a Joint Programme on Smart Grids. This joint programme consists of five sub-programmes:

- Sub-programme 1: Network Operation coordinated by Klaas Visscher, TNO (NL)
- Sub-programme 2: Energy Management coordinated by Henrik Bindner, DTU (DK)
- Sub-programme 3: Control System Interoperability coordinated by Hans de Neve, VITO (BE)
- Sub-programme 4: Electrical Storage Technologies coordinated by Seppo Hanninen, VTT (FI)
- Sub-programme 5: Transmission Network coordinated by Knut Samdal, SINTEF (NO)

Reports and presentations can be found at:
https://sites.google.com/site/eerasmartgrids/documents-download
6 A Norwegian R&D Roadmap

This R&D roadmap describes key features and capabilities of the future smart grid, briefly recounts some policy drivers influencing the future smart grid, and describes the need for high quality smart grid research in order to meet the future needs of the power industry in particular and of society in general.

6.1 Vision for the smart grid deployment

Success for smart grid deployment depends on major developments within the principles for conversion, transportation, storage and consumption of electric energy. Renewable and often intermittent energy integration will transform the system from generation follows demand to a more dynamic matching of supply and demand. Flexibility is the keyword to get a secure and reliable electricity supply. In this context, important research activities and goals are:

• Microgrids and distributed generation: Development of a concept where microgrids work reliably both in isolated and connected mode, and switch seamlessly between these modes. This will improve reliability of supply and principles will be applicable internationally and thus represent opportunities for Norwegian supply industry.

• Renewable energy integration: Norwegian hydro power with its storage capability represents an important contribution to facilitate intermittent and renewable energy sources in the European system. However, other storage options are needed and a major goal is to development strategies of optimal use of hydro power combined with other local storage, intermittent generation and load flexibility.

• EV infrastructure and charging: EVs represent a voltage quality challenge for the distributions systems as well as a flexibility and energy storage option. Development, verification and evaluation of smart charging use cases for optimal car owner, house owner and power system efficiency in terms of economy, flexibility, range anxiety, voltage quality, reliability privacy and safety are important research areas as well as options for microgrid integration.

• Buildings represent significant flexibility in the energy supply system and should be designed to work in synergy with the grids. To facilitate this, the grid must recognize the value of the flexibility. Business models will be developed to support the development and operation of zero-energy buildings and how these can support the system operation.

• Thermal energy will have an important role also in the future electricity supply system. The goal is the identify the role of thermal energy in Norway and Europe given technological developments, the current cost and regulatory framework, the expansion of renewable energy and smart grid technologies.

• ICT will be a core technology in the future smart energy supply system. It is necessary to further develop techniques and principles for: handling large amount of data, applications for control and monitoring, effective and flexible communication solutions as well as cyber security and reliability. This will be the single most challenging task and needs a multi-discipline approach.

• Business opportunities, new markets and services: In the changed environment all participants must see a value of their services and contributions. New business models must be created where
value of contribution is recognized and appropriate incentives must be developed to reach the overall goal. New services will be needed as aggregators and others acting on behalf of end-users.

- Non-technical aspects of smart grid development in Norway: Standardization, third party actors, new market models, end-use and user acceptance. Smart meters have implications for the entire energy system. The actors of the energy network are many and diverse, and rationales for implementations vary in accordance, and the stakes are high. How agendas for the energy network of the future vary, overlap and create controversies between the actors and their fundamental societal values is an area of activity which requires holistic analyses across technology and economy.

- Control and monitoring are important functions in the operation of electrical power networks. In the process of converting the power grid to a Smart Grid, these technologies must be expected to find even more widespread application. Components based on power electronics will because of the controllability be able to contribute to the system flexibility but will need robust strategies for control and monitoring.

- Standardisation is not a technical research issue in itself, but can be regarded as a consensus arena open for all stakeholders meeting to develop standards which cover a market need. Stakeholders’ often conflicting interests needs to be balanced both from a technical and economic perspective and this balancing arena calls for well documented scientific and practical knowledge from a large number of domains (transmission and distribution grid, markets, power generation, end users, smart houses, communication, IT etc.)

The vision of the deployment of the smart grid in Norway is to work in a coordinated approach and make the needed development on the mentioned topics to achieve a flexible and reliable future energy supply system.

6.2 Policy framework

The Renewable Directive has been made part of the EEA Agreement (Official Journal of the European Union, 2012), and Norway is obliged by this directive to increase its share of renewable energy to 67.5% by 2020, up from 58.2% in 2005. The scope for increased production of conventional, large-scale hydropower is limited, and the increased renewables production will therefore have to come mainly from small-scale hydro, wind and photovoltaics.

An increase in wind power production of several TWh is expected towards the year 2020 (A.C. Bøeng, 2011) due the common Norwegian-Swedish market for electricity certificates that was established in 2012 (OED, 2012) as a means to achieve the goal of 67.5% renewably energy by the year 2020.

Increased electric power production from offshore wind will require a Smart HVDC Grid in the North Sea to bring the produced power to shore reliably with a minimum of loss. Increased use of advanced High Voltage DC Transmission systems not only enables renewable power from offshore wind farms to be connected the main grid, but is also important to enhance the controllability of the power flows in the power systems (SIEMENS, 2011), and for connecting asynchronous power grids together, enabling more exchange of power between countries and regions. This would strengthen Norway’s role as a provider of ‘power on demand’ for a Europe increasingly dependent on uncontrollable renewables production.
The potential for photovoltaic technology in a country like Norway lies mainly in its nature as a distributed source of energy, which fits well with visions of energy neutral buildings. This vision is reflected in stricter building codes, see e.g. the white paper (Norwegian Government, 2012). To achieve the goal of a zero-emission building, it is recognized that building-integrated photovoltaics (BIPV) may represent a solution for a building to harvest the energy needed (B. P. Jelle and C. Breivik, 2012). For these reasons, distributed solar photovoltaics is expected to increase also in Norway, and could potentially have a huge influence on how especially the low-voltage distribution grid is built and operated.

On the level of bulk transmission of electric energy, wide area monitoring, protection and control receives considerable attention; new technologies such as phasor measurement units and Flexible AC Transmission Systems (FACTS) based on power electronics will contribute to a more stable and secure transmission grid, while at the same time enabling operation of the system closer to its limits, thus avoiding expensive and often controversial investments in large high voltage power lines.

Introduction of smart meters and other two-way communication means between the grid operators and the consumers can enable customers (both residential and industrial) to take a more active role in the power system, by actively responding to price signals and as providers of flexibility in power demand.

## 6.3 Societal challenge – the future sustainable and cost effective electricity system: Smart grids

Energy use is the predominant reason for human influence on the earth’s climate through the combustion of fossil fuels and the production of greenhouse gases, particularly carbon dioxide. This is the reason why energy and climate is singled out as one of the most important societal challenges to be solved by governments across the globe, as well as in our National Climate Agreement (2008), the New Climate Agreement in 2012, the Whitepaper for Research and Development, St.meld nr 30 (2008-2009), and the subsequent Whitepaper, Meld. St. 18 (2012–2013) *Lange linjer – kunnskap gir muligheter*.

Much attention and the largest shares of the public financial resources for R&D-D in Norway the last 8-10 years has been granted to the increase of production from (new) renewables, energy efficiency in buildings and industry, and to CCS. Decarbonizing the transport sector has had less priority in the public R&D funding, but substantial public policies have been introduced in order to increase the number of electrical vehicles in Norway and to demonstrate viable technology (Transnova). We argue that comprehensive approaches to bringing smartness to the electricity system, in combination with end-use initiatives (demand response, energy efficiency, smart house technology, EV and local storage etc.) are vital to limiting the need for capacity expansion and for reducing investments costs across the electricity chain.

The Norwegian R&D Community for Smart grids wants to contribute to, and is also concerned about the consequences of, an increased electrification of the energy system. Increased electrification is a driving force across the global energy system in the international Scenarios of IEA (ETP 2013, IPCC (Sacks). Globally, growth in electricity demand is outpacing that of all other final energy carriers.

An objective of this R&D strategy is to influence national policy makers and R&D funding bodies to enable the R&D community to meet the challenge of developing a future sustainable and cost effective electricity system.
While today's energy system paradigm is based on a unidirectional energy delivery (Large scale generation $\rightarrow$ Transmission $\rightarrow$ Distribution $\rightarrow$ End use sectors), the future sustainable electricity system needs to be a smarter, multidirectional and integrated energy system. We need to develop an optimized cross-sector integration as the choice and placement of technologies in the system will play a critical role not only for the resulting energy efficiency and CO$_2$ reductions, but also for the cost-effective development of integrated electricity systems. We need a framework of "system thinking" that can enable optimized

- cross sector integration (industrial, public, and residential sectors),
- integration with other energy carriers, e.g., district heating networks, and
- integration across the value chain of production – transmission – distribution and end use.

To this end, we need a national R&D Strategy targeting high quality smart grid research and policies for industrial innovation and development.

### 6.4 High quality Smart Grid research

The international research effort in the Smart Grid area is massive – and Norwegian research can only make up a tiny fraction of the international total. It is therefore pertinent to consider whether research on the national scale will make any difference at all. However, international research in the area is not performed with the particularities of the Norwegian energy system, industry and customers in mind, and without a Norwegian presence on the international research arena, it is difficult to understand and convey recent international results and trends to the Norwegian industry.

#### 6.4.1 The Norwegian electric power system

The Norwegian power system is characterized by the high percentage of production from large-scale hydroelectric power, meaning that the power supply is more controllable than a thermal power based system. However, it is also expected a higher penetration of other, less controllable renewables (primarily, wind and small-scale hydro). These are often located in remote areas, and may be fed into the grid at locations where the grid is relatively weak.

The Norwegian power system is also characterized by a high percentage of deferrable loads, both loads for residential heating, and in industry.

On the other hand, weather is harsh in most of the country, often causing damage to transmission and distribution lines. In the future, it will become more common that there will be one or more power sources as well as energy storage in the part of the grid that becomes accidentally disconnected. Microgrid / island mode operation and load balancing will therefore be important.

Other operational problems, such as icing on power lines, are also more prevalent in Norway than most other countries.

This description is by no means exhaustive, but is meant to illustrate that the needs of the Norwegian power system differ from those of most other countries, and therefore the research needs also differ.
6.4.2 The Norwegian customer

Many advanced functionalities in the Smart Grid will require customer acceptance and even active contribution. Well known examples include automatic metering, utilization of deferrable loads, and use of electric car batteries for storage and peak shaving purposes.

The severity of privacy and security concerns and acceptance of intrusion into private lives, the willingness to learn and accept new technology, and the willingness to invest in technology differ from country to country. The interaction between these issues and economic incentives/business models are complex. It is therefore not clear whether solutions developed for customers in the USA or Germany will be acceptable in Norway. The need for national research and expertise is therefore clear.

6.4.3 Industrial customers

It was noted above that Norway has a lot of power consuming industry that with the proper incentives may offer part of their consumption as for peak shaving or to handle other operational issues in the grid. Both the technical issues involved and the required economic incentives will differ from those of residential customers.

Issues relating to power supply to offshore petroleum platforms are quite different. Here cost, reliability and the required platform space are the prime concerns. Power supply to platforms should also be seen in connection with power export from offshore wind farms, and further connections between the power systems in countries around the North Sea.

The issues facing Norwegian industrial consumers being different from those in other countries, one cannot expect the research in other countries to fulfil the research needs.

6.4.4 Industrial suppliers

Although the supplier industry in the power sector can be said to have a low profile, it is nevertheless significant. Some companies, like Nexans, ABB Medium voltage products in Skien and Eltek, export most of their production. Other companies compete mainly in the national market, but face competition from international suppliers. What they have in common is the need to stay abreast of technological developments in order to stay competitive. This implies both the need for employees with outstanding competence, and contact with the national and international research arena.

6.4.5 Unforeseen needs

It is often said that the need for the Smart Grid is obvious, but what the Smart Grid will look like is unclear. It will be necessary with more flexible and dynamic operation to in a cost effective way meet to new challenges from increased requirements for quality of supply, more intermittent distributed generation/loads, EV charging and more power intensive devices as well as challenges related to managing aging infrastructures. Yet, how this will be achieved is not clear. Business models may change drastically (like streaming of music has changed the music business), leading to drastic changes in system operation. Such drastic changes in business models provide business opportunities, both nationally and internationally. Although Norway is a small country, there may be opportunities for Norwegian actors also in the international market. The best way of ensuring awareness of the technological changes that can provide such business opportunities is to have a strong presence in the international research arena.
6.4.6 National competence needs

Research will only open opportunities for a smarter grid. For these opportunities to be captured there must be competent personnel in industry and government. This implies the need for high quality and up-to-date education. The best way of ensuring that the education is up-to-date and reflects recent international developments, is by having educators that themselves have a presence in the international research arena and are regularly exposed to the developments there.

In summary, there are strong arguments for high quality research in the smart grid area, to fulfil both industrial and societal needs.

6.5 Instruments for High Quality Smart Grid R&D

Norway has a long and strong tradition of research and development within power systems, electro-technical components, ICT, and socio-economic research on energy. In order to stay in the front of the international research in some areas, and, at the same time conduct R&D that is useful for industry and society within the Norwegian context, the R&D roadmap suggests:

- There is a need for a well-functioning cooperation between Universities, University colleges, industry and the public sector in the creation of an understanding as to what challenges are to be solved within the development of a smarter grid. This R&D strategy is a step towards creating a better multidisciplinary understanding of the R&D challenges in this field.

- There is a need for funding schemes like FMEs that function as structuring instruments in the long term for competence building activities, research, and innovation.

- Given that the research topics, challenges and visions of the Smart grid field covers so many scientific disciplines and, because of its inter-industrial nature, there is a need for more than one FME in this area.

- There is a need for the development of research based courses and education at the higher levels of education (Master and PhD).

- There is a need for a broader offer of vocational training for the industry both at the Universities and the University Colleges in Norway.

- There is a need for a stronger public strategy and a funding scheme for the key role test and demonstration activities play in the development of smart grid solutions. Laboratory work, test and demonstration are enablers for the whole chain of Education, Research and Industrial innovation. The EU Horizon2020 program organizes its calls in two Action types:
  a. Innovation Actions = Demonstration w/ some R&D Technology Readyness Level\(^9\) (4/5) \(\rightarrow\) (≥ 7)
  b. Research & Innovation Actions = R&D w/some test/demo Technology Readyness Level (2/3) \(\rightarrow\) (4/5)

- A specific suggestion is that The Norwegian Research Council should be able to fund R&D containing some demonstration activities, and that Enova should be able to fund Demonstration projects containing some R&D. At the present there is no common strategy or coordinated funding schemes between the two Agencies.

6.6 An innovative Smart Grid Industry

To be competitive, Norwegian industry needs to be very innovative in order to counteract the generally high cost level. The smart grid domain calls for an advanced and well-educated industry which should be well in line with Norway's ambitions to be a highly educated society. A successful smart grid industry should both serve national and international markets to be competitive in the long run. In addition to the value creation of such an industry, it should be pointed out that a national industry also is important for emergency preparedness. The electric power system is a critical infrastructure, and in order to have some degree of national control over resources, supply chains and service chains it is imperative to develop and operate a robust and reliable power system. As the power system spans the whole nation, industry and service presence in all parts of Norway is required.

It should be pointed out that many smart grid suppliers (power system asset providers, software providers, telecom providers, etc.) are and will be companies belonging to large international corporations (e.g. ABB, Siemens, Alstom, Oracle, IBM, GE,...). Often such corporations have their centres of excellence for various areas located in one or a few countries in the world. For the reasons stated above, Norway should provide incentives for localization of such "smart grid centres of excellence" in Norway as well as motivate international corporations to have industrial presence in Norway.

The actions needed is to increase the public stimulus in the instruments already available for industrial development to support both the creation of new companies and make existing national and international companies expand in Norway.

However, in addition to the important role of the authorities and public agencies, it is also imperative that Norwegian DSOs take an active role in shaping their own future, by ensuring that the needed technology and market innovation actually takes place – and that such innovation reflects national needs. The option of spending 0.3% per year of the DSO asset value on relevant research – without consequences for company profits – is an innovative change of rules by Norwegian authorities overseeing a highly regulated industry, and indeed this has received positive attention internationally.

It remains for the industry to fully grasp this opportunity, to get important research and development done in cooperation with suppliers and research providers. In this, the electric power industry should take inspiration from the oil & gas industry, which both through its own research and by acting as technologically demanding customers for equipment suppliers, has elevated both itself and the national supply industry to become the most technologically advanced in the world.
7 References


[16] NVE (Norges vassdrags- og energidirektorat), Havvind – Forslag til utredningsområder, 2010


### Table 2: Number of people involved in various research topics related to Smart Grid, as of the Summer 2013.
(Fac. = permanent faculty, Temp. = temporary research staff (incl. PhD, PostDoc)).

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