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On experience of smart grid projects in Europe and the Swedish demonstration projects

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Konstantinos Chatziioannou
Jan Guštinčič
Lina Bertling Tjernberg

Division of Electric Power Engineering
Department of Energy and Environment
Chalmers University of Technology
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SE-412 96 Göteborg

Sweden

Abstract

Renewable energy sources are expected to play a significant role into the future power system. The variable and at many cases not easily predictable production of electricity will pose a threat on the reliability and efficiency of the current electricity grid. Hence, there is great need of measures that will be able to handle these fluctuations of the production systems. Transforming the current grid to become a more intelligent system that could predict the variations as well as exploit hours with lower demand and, hence, lower electricity prices is one way to deal with the problems caused by the technology shifting. New projects that address those issues are constantly under deployment in recent years. In Sweden today there are three large demonstration projects, the *Sustainable City Hyllie*, *Smart City Gotland* and the *Stockholm Royal Seaport*.

This paper investigates the technologies used in the three projects, how the goals that were set in the beginning of each project are being fulfilled, as well as the ways that the different actors are copying with the challenges and problems faced. The approach that was used includes a comparison of the projects with other successful finalized projects carried out throughout Europe. The methodology was divided in three smaller steps. The first step was the collection of data about all the technologies and all the investigated projects in Europe and Sweden. The second step was to construct a table where a significant number of technologies used by the projects were listed alongside with an indication on whether the implementation of the technologies is finished or ongoing. The results for the ongoing Swedish demonstration projects were iterated and checked by conducting interviews with key people inside the projects. Finally, using the data from the table some conclusions and results were extracted in the final part of the report.

Index Terms: European smart grid projects, JRC, Smart Grid, Swedish large scale demonstration projects, Hyllie, Smart Grid Gotland, Stockholm Royal Seaport

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List of Nomenclatures

CHP= Combined heat and power

DER= Distributed energy resources

DSO = Distribution System Operator

EU = European Union

IEEE = Institute of Electrical & Electronics Engineers

ICT = Information and Communication Technology

ISGT = Innovative Smart Grid Technologies

JRC = Joint Research Centre

RES = Renewable Energy Sources

R&D= Research & Development

SAIDI =System Average Interruption Duration Index

SG = Smart Grid

US= United States

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1 Introduction

1.1 Background

The use of renewable energy sources for electricity production has become more and more widespread over the recent years. Therefore, the need to have a more effective electricity grid that can adjust to the fluctuations of the production as well as to make more efficient use of the cheap electricity is increasing. As a result of this, new projects that want to address these issues appear constantly. In Sweden today there are three large demonstration projects, namely the *Sustainable City Hyllie*, a newly-constructed district within the city of Malmö which aspires to cover all of its energy demand by renewable energy sources by 2020, *Smart City Gotland* which involves a lot of wind power production in the island of Gotland and the *Stockholm Royal Seaport* that tries to lower CO_2 emission, while developing a smart city area near the seaport of the Swedish capital city. The objective of this paper is to investigate the technologies used in these three projects, find whether the goals that were set in the beginning of the project are being fulfilled and how, as well as see the ways that the different actors are copying with the challenges and problems faced and identify possible solutions. The approach that was used includes a comparison of the projects with other successful finalized projects carried out throughout Europe.

1.2 What is Smart Grid?

Smart Grid expresses today's developments of the electric power system targeting a sustainable energy system. Some of these developments involves new usage of electricity e.g. in transportation sector using electrical vehicles for storage, and some are related to developments of existing systems with new technology e.g. continuous metering of electricity. There is no single true definition of the concept. In this study two definitions are selected presented by EU and IEEE, whose involvement to smart grid development has been profound:

"A smart grid is an electricity network that can integrate in a cost efficient manner the behaviour and actions of all users connected to it - generators, consumers and those that do both - in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety." [1]

"The "smart grid" has come to describe a next-generation electrical power system that is typified by the increased use of communications and information technology in the generation, delivery and consumption of electrical energy." [2]

2 Smart grid projects in Europe

The Joint Research Centre (JRC) is a Directorate-General of the European Commission, which provides technical and scientific advice to support a wide range of EU policies and is currently compiling a database with smart grid projects in Europe. A new version of this database has been recently released titled “Smart Grid projects in Europe: Lessons learned and current developments” [3]. A snapshot of this study was presented during a panel session on “Smart Grid in Europe” held during the recent IEEE ISGT US 2013 in Washington [4]. According to that report, 281 SG and R&D projects were recorded in Europe at a total cost of 3.9 billion€. Some of those finalised smart grid development projects are briefly presented in this section of our report.

Model City Mannheim (DE)

In this project, 200 households were equipped with appliances, where a home energy controller was in charge to optimize the use of appliances with variable usage times, such as dishwaters and deep freezers. This resulted in a 6%-8% load shifted to low tariffs and a load management potential of 0.1 kW per household. In addition to that for about 30 minutes nearly 20% of installed capacity could have been used as a positive balancing power through switch-off or delayed switch-on. Quite impressive is the fact that 80% of the customers that participating in this project claimed that they are not willing to pay money for the electricity consumption data and its visualization.

On the other hand, a recent study [5] shows that the savings of shifting the loads based on hourly pricing in the day-ahead spot market in monetary terms does not exceed 1.7% of the total electricity costs, when electric heating is also included. When only dishwashing and laundry is shifted the savings vary from 0.5-1.2%. There is also a risk that the demand might increase during hours of the day that the electricity price is low.

E-telligence (DE)

The project, which was carried out in Germany, explored the approaches using modern ICT and advanced operation to improve current energy supply system to provide flexibility of demand according to the fluctuations of RES generation. In the system there were involved 650 households with smart meters/monitoring, dynamic rates incorporated, a demand response integration and an integration of distributed energy resources by means of virtual power plants bundling resources and balancing fluctuating generations by incorporating costumers with shiftable loads (with renewable sources included). A 12%-13% monthly reduction of energy consumption has been demonstrated, with a further telecommunication expertise.

Energy demand project (UK)

The project explored the responses of 60000 households to different means of visualization of energy consumptions (smart meters, home displays). The in-home displays showed a saving up to 11% energy.

Grow-Ders (EU)

This project investigated the implementation of (transportable) distributed storage systems in the networks. The key findings are that the current market does find storage systems very attractive, but economically not feasible yet and with legislation uncertainties.

Web2Energy (EU)

The Web2Energy project is directed to implement three fundamental points: Smart Metering, Smart Energy Management and Smart Distribution Automation. In this project all three pillars of smart distribution required the information exchange between the users of the network like consumers, producers, terminals, control center of the network operator, traders and VPP.

The project included three days ahead tariff zones which are dependent on the electricity prices on the spot market and the intensity of wind and sun shine. This implied on an interval of 3 months a 3% average decrease of the energy consumption in households. An interesting point is the energy reduction achieved during intensive demand, by shifting the load from a higher phase to a lower one.

Cell-Controller Project (DK)

The aim of this project is to set out a control system capable of coordinating DER in order to support DER-based ancillary services and to safely island the study region, maintain autonomous operation and resynchronize with the main network. The system included substations, CHP plants, wind turbines, load feeders and numerous additional assets.

While islanded, the system maintained stability of the cell until the cell was requested to rejoin the grid at which time the system would resynchronize with the main grid, re-connect, and return to normal operation. In addition to that the project demonstrated the successful technical demonstration of active distributed control of large power system over existing communications infrastructures and controls in the loop testing.

Premio (FR)

The Premio project develops and tests a VPP, which integrates around fifty Distributed Resources (small generating plants using renewable energy), whose performance is being investigated. Important load reductions were observed (up to 40%). The results showed that the control of demand response must be further improved to provide more precise responses to the requests and that the differences between the types of DER must be considered in order to use results as leverage to an enhanced performance.

Ikaria (EL)

Ikaria Island, in Greece, has integrated a renewable energy network, whereas the 94% of the energy demand is covered by diesels and 6% of wind. The aim of the project is to turn the percentages. The key results are that wind power and hydroelectric generators showed a good integration in the Smart Grid Master Control installation (with an intelligent power dispatcher). This project can be a pilot for the implementation of hybrid systems in other islands experiencing the same problems.

Pegase (EU)

The Pan European Grid Advanced Simulation and State Estimation project aimed removing algorithmic barriers related to the monitoring, simulation and optimization of very large power systems. The key finding of this project was the production of powerful algorithms and full scale prototypes validated on the EU transmission network to enhance the cooperation among transmissions system operators, for the real time control and operational planning.

Regmodharz (DE)

Regmodharz project aims to a technical and economic development and integration of distributed energy sources by deploying modern information and communication technology with the contribution of wind farm operators, universities, research institutes, grid operators and energy suppliers.

The project demonstrated that the key to a successful storage requirements can be achieved only trough short-term accurate wind forecasts. Loads shifts on the consumer side are necessary to help improving voltage regulation in the distribution grid and compensate the forecast errors.

Edison (DK)

In this project the main focus has been put to electric vehicles integrated in the grid, with an optimized charging. The main technical problems result mainly in grid services (converters, inverters). The technologies of the Edison project are tested on the island of Bornholm.

3 Large scale demonstration projects in Sweden

The Swedish on-going large scale demonstration projects are still in the early stage of deployment and testing today, thus, there are no solid results yet, in contrast to the European projects mentioned in chapter 2. In the following section, the research carried out about the current and future plans of all the above mentioned projects is presented.

3.1 Hyllie: A new green and sustainable city area in Malmö

The Hyllie project is about a new integrated "green" area of Malmö, which involves the construction of new apartments and work places in an innovative energy network. In this project the main goal is to develop sustainable energy resources by using most of the existing infrastructure. With a collaboration of the E.ON company and overall secured funding of 23 MEuro the project wants to provide solutions to the most common technical issues concerning energy saving and "smart city development", such as [6]:

- customer control of heat and electricity consumption,
- distributed heat and energy generation,
- smart grid solutions (DH and electricity),
- sustainable mobility solutions,
- CO_2 storage and distributed energy storage.

At the end of 2009 the City of Malmö initiated both the "Environmental Program for 2009-2020" and "Energy Strategy Malmö (the "Climate contract"). The following information that is presented is based to large extend on the *Sustainable Contract for Hyllie* [7] that was signed by the three main actors involved in the project (City of Malmö, E.ON, VA SYD).The aim of the program is to make Malmö the best sustainable city development in the world by 2020, while fulfilling four overall environmental goals, which include climate, environment and a sustainable utilization of natural resources. Hyllie is Malmö's largest development area. It is an important transportation hub and it's located very close to Copenhagen, which makes this area one of the most dynamic ones in Europe [8]. By the end of the project it is expected to have approximately 9000 residential units as well as an almost equal amount of workplaces. In order to reach the goals set by the three parties that signed the program very resource efficient structures for transport, energy and land need to be adopted. The long-term vision for Malmö (2030) is to achieve a 100% supply of its energy needs by renewable energy sources, while securing efficient and safe energy consumption. The energy problem solution is supposed to have its origin on a global perspective, which means that a special attention is paid to the infrastructure that is already on site (e.g. district heating or incineration plants) [8]. An additional focus of the project is to achieve a positive energy balance for the district of Hyllie, i.e. the electricity production must exceed the consumption.

A summary of the main goals that have been set is presented in the following points [7]:

- The energy supply in Hyllie is expected to be comprised by 100% renewable or recovered energy by 2020
- Infrastructure for electricity, gas, heating and cooling systems is expected to be developed and integrated as well as an optimal communication between those systems, through smart infrastructure ("smart grid")
- Emphasize the use of thermal energy (solar, large scale heat pumps). [8]
- The buildings in Hyllie are expected to be efficient, low energy as well as to have ability to exploit the possibilities offered by the smart infrastructure network.
- Local production of renewable energy sources, such as solar and wind energy, is expected to cover much of the areas energy needs.
- Travel is expected to be largely dependent on foot and bicycles, as well as an extended public transport network.
- Hyllie is expected to become an area of testing and demonstrating innovative climate-smart solutions.

The energy concept is characterized by high cooperation between different types of infrastructures, including waste, water and sewage. Due to the fact that a vast amount of the energy consumed is expected to come from renewable energy sources, there will be set requirements for distributed generation in buildings. Additional efforts will be made for the best possible utilization both in existing distributed and centralized production. Thermal storage (by using the structure itself to store the energy) , which is planned to be achieved by using meters, is also meant to play an important role [8].In the following years the planned major expansion of the wind power production is expected to have a considerable influence on the grid performance, which needs to be investigated. Wind turbines are supposed to be both connected to the national grid and to the Hyllie network. The wind power expansion is meant to be both within the physical borders of Hyllie and in other (offshore and onshore) sites. The final aim of it is to test smart grid functions in the grid for a further understanding what the potential can be [8].In order to keep the balance between electricity consumption and production, the three actors involved in the project are supposed to create the conditions for smart and efficient use of energy as well as make investments in energy saving solutions for storage and energy control, like the use of electric vehicles [8].

The different actors engaged in the Environmental Program for 2009-2020 have also agreed in four key focus areas, in order to succeed, eventually, in the overall goals of the program.

A. Energy supply – electricity, heating and cooling requirements
B. Infrastructure – distribution solutions and interaction between systems and properties
C. Transport solutions
D. Consumption – automation and control system, behavior and lifestyle issues

3.2 Smart Grid Gotland [9] [10]

In the Smart Grid Gotland project large quantities of renewable energy sources are integrated in the grid by using modern technology. Customers are involved in the electricity market and they can monitor the energy usage 24 hours a day and adjust the consumption to the current price of electricity. The project has three overall objectives:

1. Cost efficiently increase the hosting capacity for wind power in an existing distribution system
2. Show that novel technology can improve the power quality in a rural grid with large quantities of installed wind power.
3. Create possibilities for demand side participation in the electricity market, in order to shift load from peak load hours to peak production hours.

The three objectives have been translated to the following measurable objectives:

- Increase the hosting capacity of wind power from 195MW with 5 MW by use of load shift.
- 20% reduction of SAIDI, in the grid between substations in Källunge and Bäcks.
- Active participation of 30 industrial companies.
- Attract 2000 households to participate in a market test under market driven conditions.
- Active customer will contribute to a load shift of +/- 10%

The three overall objectives are demonstrated in three main sub-projects. The main goal for *sub-project wind power* integration is to optimize the hosting capacity for wind power in an existing distribution grid and to achieve this goal in a cost efficient way. A main challenge of this concept is to keep the load balanced and not further decrease in the case there's a large quantity of wind power production. Wind power forecasting is also going to play an important role in the production mix for the operation planners, since the more accurate the forecasts become, the more cost-efficient the planning of the operating power plants will become. Therefore, the costs for the electricity consumers will drop as well [11]. The objective of the *sub-project power quality* is to show that new technology can improve the electricity quality in a rural grid with large quantities of distributed power production to a low socioeconomically cost. The objective for *sub-project market test* (which is planned to start autumn 2013) is by active participation on the electricity market to make it possible for customers to lower their electricity costs and thereby lower the system costs.

3.3 Stockholm Royal Seaport [12]

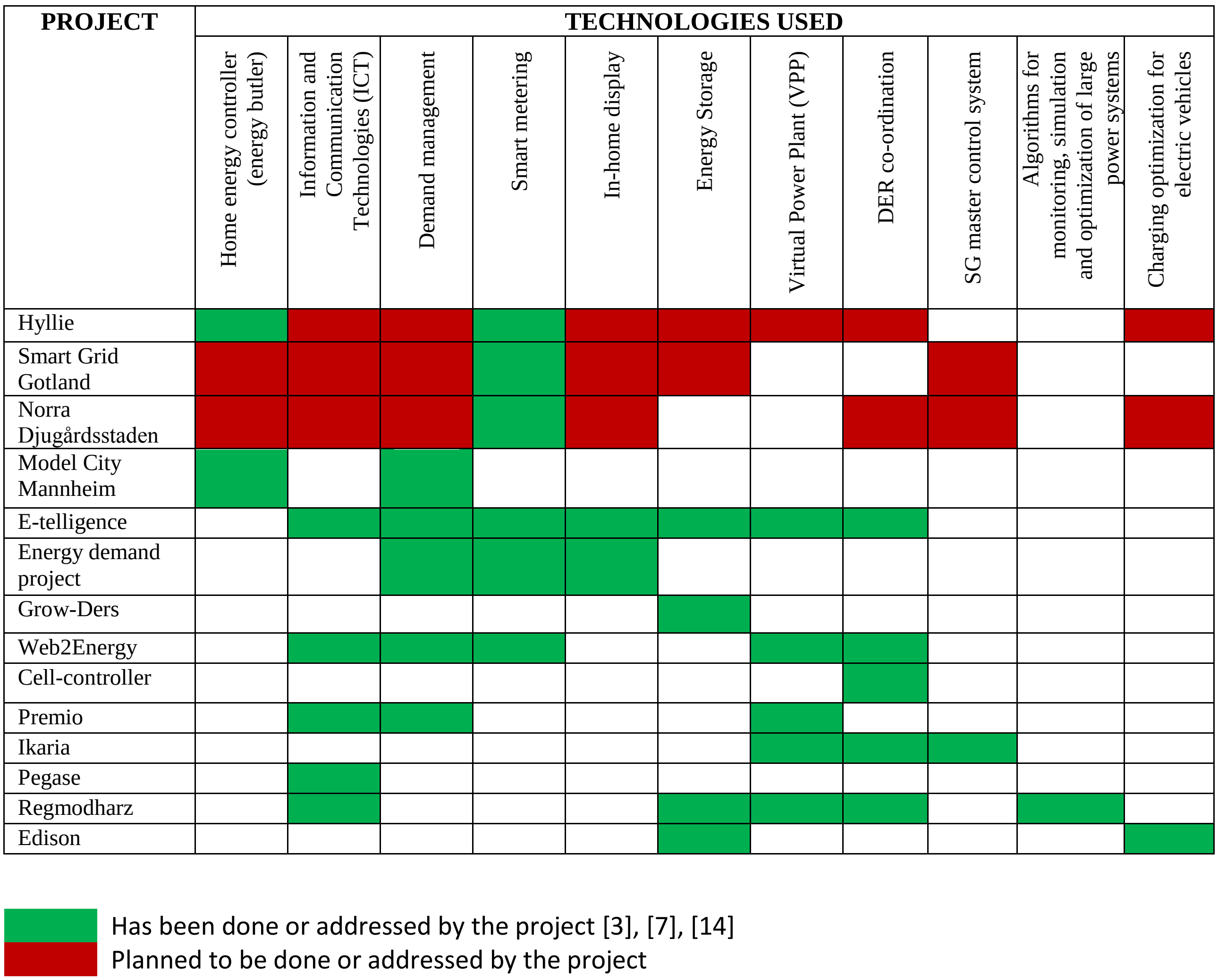
The Stockholm Royal Seaport (Norra Djurgårdsstaden) project is one of Europe's most extensive city development projects. Its primary goal is to reduce CO2 emissions and lower electricity prices which is expected to be achieved through electricity generation using solar cells, local energy storage, control systems that enable a more efficient distribution of energy consumption, individual measurement and consumption visualization, equipment for control, follow-up and metering and stations for charging electric vehicles [13]. In this case storage is not implemented in the project due to the non-economic feasibility and need for that as there is a CHP plant that could be started in case of instant peak load demand [13]. Another focus is the integration of the port electricity needs in the smart grid context [13]. The first phase of the houses occupancy started in 2012 and it is expected that construction of the entire area will be completed by 2030. Norra Djurgårdsstaden will offer 10 000 residential units and 30 000 offices, as well as a new port facility.

The study of the market based pricing also plays an important role in this project. Thus, one goal of the Royal Seaport project is the use of appliances in private houses to be optimized in regards to price convenience. A single family house is equipped with all the technologies that will make this optimization feasible, acting as an actual demonstration of the project.

4 Results and Discussions

After accessing available bibliography about the above-mentioned projects, the result was the creation of the following table, which illustrates the different methods and approaches used in the studied projects throughout Europe.

Table 1 Studied projects and technologies used by each one



The following technologies have been studied:

- **Home energy controller (energy butler)**: a device that optimizes heat consumption and the use of appliances with variable usage times, such as washing machines and deep freezers, in response to price signals [3] [8].
- **Information and Communication Technologies (ICT):** devices that monitor real time electricity consumption and prices according to the market [3] [8].
- **Demand management:** combined smart meters and in-home displays that visualize the energy consumption [3]
- **Smart metering:** an electrical meter that records consumption of electric energy in intervals of an hour or less and communicates that information at least daily back to the utility for monitoring and billing purposes. [15]
- **In-home display:** A home energy monitor provides prompt, convenient feedback on electrical or other energy use.

- **Energy Storage:** Energy storage is accomplished by devices or physical media that store energy to perform useful operation at a later time. Storage integration is fundamental when it comes to provide the grid ancillary services and to smooth deμand flexibility [3] [16]
- **Virtual Power Plant (VPP):** A virtual power plant is a cluster of distributed generation installations (such as micro CHP, wind-turbines, small hydro, back-up gensets etc.) which are collectively run by a central control entity. The concerted operational mode delivers extra benefits such as the ability to deliver peak load electricity or load-aware power generation at short notice [17].
- **DER co-ordination:** The individual capability of distributed energy resources to provide grid support might be very small, but their presence in large numbers in many distribution networks implies that, under proper coordination they can collectively become an asset for providing ancillary services [18]
- **SG master control system:** a central smart grid management system
- **Algorithms for monitoring, simulation and optimization of large power systems:** Use of algorithms related to the monitoring, simulation and optimization of very large power systems (on full scale prototypes validated on the European Transmission Network to enhance the cooperation among transmission system operators for the real time control and operational planning of the system.) [19]
- **Charging optimization for electric vehicles:** Technologies that enable low-cost, efficient, plug-and-play integration of electric vehicles into the power system. [20]

By considering Table 1 it is clear that while the JRC projects have been completed, Swedish smart grid projects are still in their first development phases. In all of them only a minor part of the final plan is already constructed and working, while in the rest of the European projects improvements, expansion and further optimization of the different technologies are yet to be implemented. The Swedish demonstration projects are more extensive and once completed will be using a more widespread collection of technologies. However, this must be also proven in the field, because most of the technologies are still in the phase of testing, planning or even in some cases just in paper. The three projects are also benefitted from the fact that already 99% of the Swedish buildings are equipped with smart metering since 2009 due to the legislation of the country [21].
There is a very broad mix of technologies used according to the objectives of each project. Out of the 14 investigated projects only one uses algorithms to optimize the operation of the power system. *SG master control systems* and *charging optimization technologies for electric vehicles* are not yet very common among European smart grid projects, although on the other hand the Royal Seaport project has plans to include both technologies, while Hyllie will include "smart charging" facilities and Gotland a master control system. This means that Sweden and the Swedish projects are some of the most advanced in these areas. Some other technologies that Sweden is more advanced than the European projects that were studied are *home energy controllers, smart metering* and *in-home display*. On the other hand the most popular technologies right now including the three Swedish projects are *ICT* and *Demand-side management* Figure 1 illustrates this comparison.

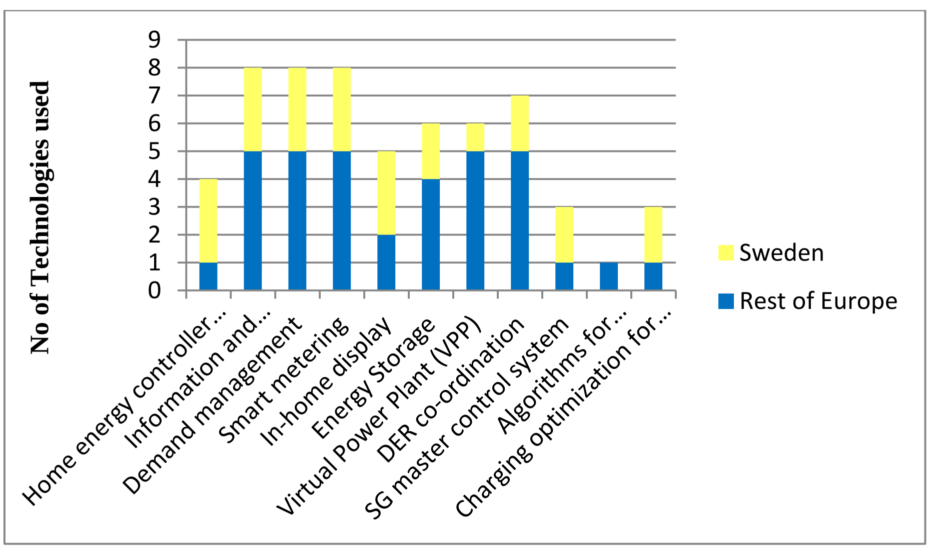


Figure 1 Number of projects using the studied technologies in Sweden and across Europe

The Hyllie project is currently the most advanced of the ongoing demonstration projects in Sweden. There is an *energy butler* installed in every building that optimizes the usage of devices with variable loads as well as the heating loads. It is the only one among the three studied Swedish projects that plans to use a *VPP*, in order to control and co-ordinate the electricity production from a cluster of renewable energy sources. The energy storage will also be distributed, meaning that whenever a customer is in need of excess electricity, they could use the nearby stored electricity, which was produced by wind, solar or other renewable energy sources at a time that the production was higher than the demand.

Smart City Gotland is mostly based on wind-power production and the constructions of new wind farms and intelligent grid development will intensify in September 2013. Two *HVDC* cables already exist in the island, one that connects the island to the Swedish mainland and one connecting two points inside Gotland with the aim of providing voltage support to the growing wind power of the island. The main challenges that the project is facing is the little interest in investing in wind power right now, because of the low electricity prices. From a technological point this project aims to answer other questions as about innovative way of energy storing when HVDC cables are used (e.g. in this case storage systems will be directly connected to one end of the cable). As a conclusion this project will provide answers about the behavior of an islanded system, especially when it comes to intermittency due to high penetration of renewable sources.

Despite being the first project to be launched, the Royal Seaport presents less advanced technologies compared to the other projects. This is due to the fact that the energy system mix in Stockholm is different compared to other cities. It's interesting, for example that in this project a few technologies have not been considered at all, like the e*nergy storage.* By recalling what has been stated above this is due to the fact that the Stockholm city center has a CHP plant which can be used in the case of peak loads. This means that energy storage is currently technically and economically not cost-effective. We believe that investing in storage technologies becomes cost effective only in the case that there is no electricity production plant that can fulfill the needs of energy when renewable energies cannot provide it. A similar explanation can be stated for the fact that in this project there is no *VPP*. Again, this is due to the fact that the energy mix of the plants in Stockholm already fulfills the necessary peak demands when necessary. However in this project there will be used electric vehicles so they will be useful in order to study what's the grid response to a more flexible and demanding energy system. The Stockholm project will be unique in a sense of studying whether renewable energy production can provide the necessary energy in the case of instantaneous peak loads due to large cruise vessels entering the port (in the order of 50 MW) [13].

As a conclusion it could be said that among the Swedish large demonstration projects, Hyllie is the one that presents most innovations on most technological fields, since it covers more of the technologies when it comes to residential development and the integration of renewable resources. However, more focus is needed when it comes to the integration of wind power in urban centers, as well as solar energy since renewables are expected to have a constant increase in the following decades. In this case grids will be heavily stressed and coal, natural gas and oil will be less used for peak loads due to this gradual shift to renewables. Therefore, a huge attention must be paid to storage, too. In Sweden this technology is not sufficiently developed, because of the large presence of CHP plants. Another reason why the storage systems lacking is its high cost, therefore investments are often not profitable and with the current state of the art, economically risky.

All in all, smart grid technologies are right now on the top of both the European and the Swedish agenda and major development are going on in a national and European scale. The annual report of the Swedish Co-ordination Council on smart grids has been recently released and it is part of a national ongoing plan to identify relevant projects in order to create a database that includes all the Swedish smart grid developments [22].

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