Smart Distribution Grids Power Europe's Transition to Green Energy

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DSOs - the backbone of the energy transition

By Klaus-Dieter Borchardt, Director at the European Commission's Directorate on the Internal Energy Market

When the European Commission presented its Winter Package of energy legislation in November 2016, much attention was given to issues such as market integration, consumer empowerment and ambitions for renewables and energy efficiency. Far less attention was paid to the infrastructure that enables the ongoing transition of the energy system to take place, i.e. the distribution networks.

Distribution networks are rarely the centre of heated public debates. However, their crucial role in facilitating a transition towards cleaner and more distributed energy sources is widely recognised among both market players and policy makers.

Distribution System Operators (DSOs) will need - even more than today – to be the flexible backbone of the electricity system, dealing with both fluctuating production, and flexible consumption at the same time. This requires policies which incentivise investments in innovation, maintenance and expansion of distributions grids. And it requires that the voice of DSOs is clearly heard in both Brussels and European Capitals.

The European Commission has opened this debate with proposals on establishing a European DSO entity, provisions on stronger cooperation between TSOs and DSOs, perspectives on active distribution system management and a number of other relevant topics.

The legislative details of the Winter Package will be subject to intense negotiations over the coming 1-2 years. Drawing on concrete experience from member states will be key to ensuring the best possible outcome. In this way, we can ensure that the backbone of the energy system is surrounded by the muscles necessary to drive the energy transition forward.

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Did you know that...

- the Danish distribution grid is 166,000 km long (= four times around the world)
- there are 3.25 million electricity meters and customer relationships with DSOs in Denmark
- there are 800,000 cable cabinets and over 70,000 transformer stations located around the country
- approx. 14 per cent of a household electricity bill goes to distribution (and 57 per cent to the government)
- operating costs per grid km have fallen by almost 40 per cent over the last ten years

Illustration: Danish Energy Agency

The electricity system is turned upside down

From 100 per cent coal-fired power plants: Thirty years ago, virtually all the electricity in Denmark was produced in a few central power plants. Some of these coal-fired plants are now closed and most of the others have been converted to biomass.

To 56 per cent green production: In the last few decades, 5,000 wind turbines have been erected, covering the equivalent of 42 per cent of electricity consumption. Add to this the several hundred smaller combined heat and power (CHP) plants and almost 100,000 solar cells. In all, 56 per cent of Danish electricity consumption is covered by green electricity.

Cheap electric grid

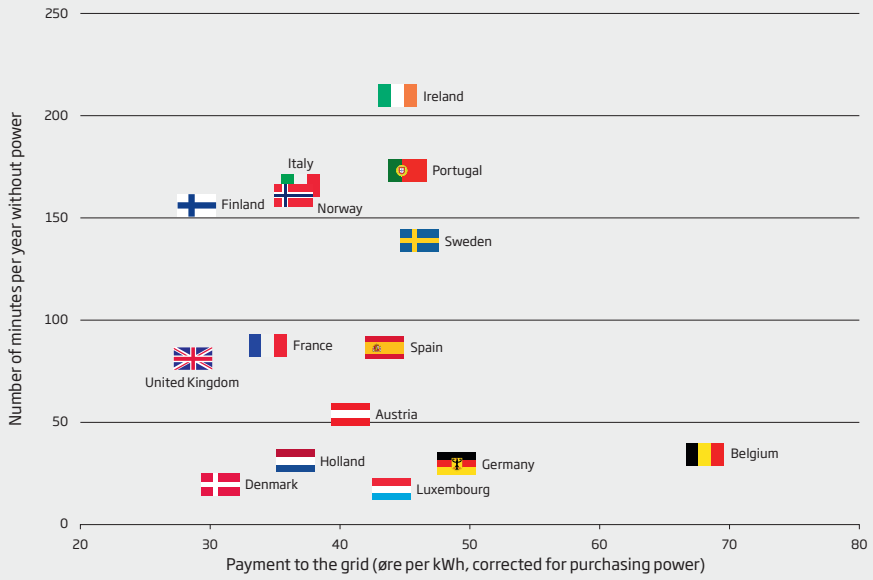
The transmission and distribution of electricity in Denmark costs only approx. 30 øre per kWh, thus offering households and businesses some of the cheapest tariffs in Europe. This is evident from the tariff level comparisons which Eurostat publishes each year in "Energy Price Statistics". These calculations show that the Danish grid is well managed and efficient, which is beneficial for families and the competitiveness of Danish companies. The success is due to the fact that Danish DSOs invest over DKK 2.2 billion every year in infrastructure.

Head of department Filip Sundram from the Danish Energy Association believes that innovation in the regulatory framework of DSOs is necessary:

"The challenges facing the DSOs are not insurmountable, but the solutions require investment and new, innovative solutions. Therefore it is important that the DSOs are not punished by regulators – but on the contrary are encouraged – to carry out innovations which will benefit society," says Filip Sundram.

Denmark's grid delivers superior quality – at discount prices

Source: Eurostat and CEER



European trend: Local production

All EU countries invest in renewable energy. Germany is leading the way and setting a good example, having increased its capacity of renewable energy from 11,400 MW in 2000 to 97,500 MW in 2015. The share of green kilowatt hours has increased from 7 to 30 per cent in 15 years. Source: BDEW.

Policy must adapt:

Tremendous amounts of wind energy

A stiff wind often blows across northwest Jutland, and wind turbines, solar cells and local CHP plants cover the equivalent of several hundred per cent of the annual electricity consumption. Over shorter periods, the degree of coverage can reach 1,000 per cent.

Jysk Energi, which has approx. 30,000 customers, operates the distribution company NOE Net and is co-owner of the 60 kV company Vestjyske Net. Together, they supply approx. 430 GWh of electricity to their customers. Local electricity production is around 935 GWh and two new wind farms are on the way; Vemb Nordøst Wind Farm at 40 MW and Hoager Wind Farm at 41 MW.

"During the weekends, when it is windy and and industrial consumption consumption is low, we sometimes export ten times as much power as our customers consume. With the two new wind farms, things will be more extreme", says technical manager Per Strøm Kristensen of NOE Net.

At NOE Net, wind turbines, CHP plants and solar cells at certain periods cover the equivalent of 1,000-1,200 per cent of the local electricity consumption. Wind turbine capacity alone is close to 400 MW, and with 7-8 large wind turbine and solar cell projects in 2017 and 2018 - including Vesterhav Nord at 200 MW out in the North Sea - capacity will increase up to 700 MW.

Renewable energy penetration in northwest Jutland is far above the national average and this should be reflected in the regulatory framework, according to Jysk Energi:

"We support the green energy transition, but our consumers pay too high a price for grid losses and for operation and maintenance, and this is unreasonable. We send off a very large part of our production to other parts of the country, and the future regulatory framework for DSOs should take account of this", says managing director Lars Naur of Jysk Energi.

Data centres choose Denmark

A green, highly reliable supply of electricity at reasonable prices, a modern fibre network, well educated workforce and stable business climate. These are just some of the explanations given by the likes of Apple and Facebook for choosing to to make significant investments in very large data centres in Denmark. While Apple has chosen Viborg as the location for a data centre that will probably use 0.7-1 TWh/year, Facebook has decided to locate in Odense on the island of Funen.

"We are proud that a large company like Facebook has chosen Funen of all places. It is a stamp of approval for the Danish and Funen electricity supply. We are pleased that we can support the Facebook facility. It is an important project to advance the development of infrastructure on Funen," says Bent Agerholm, Group CEO of Energi Fyn.

Lars Aagaard, managing director of the Danish Energy Association, mentions that Denmark's energy system has been named the best in the world by the World Energy Council due to its green energy, reliability of supply and low prices.

"If we are to maintain our leading position in green energy, the next step for our politicians is to change our energy tariffs so that the increasing demand for greener power is no longer taxed more heavily than oil and gas, which makes no sense at all," says Lars Aagaard.

308 per cent green electricity

Island energy: Undersea cables to the mainland are one of the reasons why Samsø has succeeded in integrating huge amounts of renewable energy, saving millions of DKK on the purchase of fossil fuels – and becoming world famous.

For decades, Samsø "imported" electricity via undersea cables and imported oil brought in on ships. Samsø thus "exported" a great deal of money away from the island – money that a local community could otherwise have benefited from.

Samsø itself now produces much more energy than is used on Samsø and the neighboring island of Tunø, turning electricity into a source of income. The local district heating plants buy straw from Samsø, so all in all the green island has reduced its fossil fuel costs quite considerably.

"I estimate that this amounts to about DKK 10-15 million per year," says director Søren Hermansen of the Samsø Energy Academy.

For an island municipality with approx. 3,700 inhabitants, this is quite a lot of money, but the financial returns from establishing itself as a renewable energy island do not stop there.

The story that wind turbines and a few solar cells cover the equivalent of 308 per cent of Samsø's electricity consumption combined with CO_2-free district heating is extremely powerful, so Samsø welcomes several thousand energy tourists every year – including ministers, ambassadors and TV stations. This provides employment at Samsø Energiakademi and at local hotels and restaurants. In all, this equates to 30 new full time jobs.

In addition, active people on the island are able to obtain ongoing funding for projects. Recently, Samsø Energiakademi received funding from the KR Foundation with "Global Expansion of Sustainable Community Projects" to establish energy academies in two locations in the USA – Hawaii and Maine – as well as in Australia, Japan and the EU.

"I know that in a world where fossil fuels cover 80 per cent of energy consumption, this perhaps does not have much of an impact impact, but it offers faith and hope for a more sustainable future," says Søren Hermansen.

DSO: No problem

To succeed in becoming world famous in the field of renewable energy, you need strong local engagement, with many residents thinking "what is good for our community". Other factor is that back in the 1990s Samsø was named a national renewable energy island, which brought in extra funding.

It helps that Samsø has good grid connections to a much larger electricity system. Samsø has two undersea cables to Jutland, thus forming a kind of ring connection with a high security of supply. Grid manager Michael Grønhøj of NRGi Net in Aarhus explains that the significant share of green electricity on Samsø does not cause any technical problems.

"We have a strong underlying grid and production on Samsø is relatively small," says Michael Grønhøj.

To continue creating value for the island – and to remain in the international spotlight – Samsø must continue to evovle. Wind turbines on land and out at sea are being supplemented with solar cells, energy efficiency renovations, heat pumps, electric vehicles and other green initiatives. The ferry to Jutland now sails on liquefied natural gas (LNG) instead of diesel, but the plan is to move over to locally produced biogas and electricity.

"The next thing will be to analyse the possibilities within the bioeconomy and circular economy," says Søren Hermansen and mentions that it may be sensible to cut back on the straw in district heating plants by installing heat pumps and use the straw for biogas production instead.

In common with other communities far from major urban areas, Samsø is threatened by a vicious circle in the form of residents moving away and fewer stable taxpayers. Whether this is due to activities on the renewable energy island is difficult to say, but more people are moving to rather than away from Samsø. The challenge is that too few children are being born.

The story of an island with over 100 per cent green energy and ambitions to become fossil-free by 2030 is so powerful that Samsø welcomes several thousand energy tourists every year – including many TV stations. Photo: Jørgen Bundgaard/Samsø Energiakademi

Energy park harvests power from the wind and sun

A new wind farm and solar park increases renewable energy penetration to 58.5 per cent in Ringkøbing-Skjern municipality. The local DSO, RAH, has established the necessary infrastructure – including ten kilometres of high-voltage cable.

White clouds sweep across the sky casting shadows on the 22 Vestas turbines, each with a capacity of 3.3 MW, and 69,000 solar panels in what Ringkøbing-Skjern municipality calls "Denmark's largest energy park". The grass is green, and despite the the weather, both solar panels and wind turbines produce plenty of electricity for the grid.

We find ourselves in Nørhede-Hjortmose, just east of Ringkøbing, in a wide open area, close to the North Sea and far from the nearest neighbour. Here, private investors have installed 72 MW of wind energy and 15.2 MW of solar cells, thus contributing to the municipality's goal to be 100 per cent self-sufficient in green energy by 2020.

Thanks in part to the electricity produced in Nørhede-Hjortmose, the residents and businesses of Ringkøbing-Skjern municipality have reached an estimated coverage of 58.5 per cent, according to the latest figures.

"Yes, it is a truly spectacular park. The solar cells are installed between the wind turbines and do not bother anyone", says technical manager Per Nielsen of RAH, who are responsible for the aggregation network and connection of the solar cells to the 10 kV grid.

A race against time

Ten local investors stand behind Hjortmose Solenergi, which has put DKK 125 million into the project through loans from local banks. The idea of having so many solar cells emerged in 2012 during construction of the wind farm, but it was not until 2015 that things gathered pace.

The project was a race against time because the subsidy for solar cells would fall by 14 øre/kWh at the end of the year. With an expected annual production of 16.2 million kWh, this was equivalent to DKK 22.6 million over the ten years that the total subsidy of 102 øre/kWh will run. The DSO therefore helped to speed up the process.

"We managed it thanks to the excellent cooperation between all parties – including the municipality. We all have a good relationship and have established a visitor centre jointly with the plant owners, Vestas and RAH", says Per Nielsen.

The dark blue solar cells were transported in on three container ships from the Chinese solar cell manufacturer Talesun. A second key component, the 750 inverters at 20 kW each which ensure that the current is converted from DC to 230 volts AC, was driven up on trucks from SMA Solar Technology in Germany.

Work began on 1 October 2015, with the local electrical company BroCons laying 320 kilometres of cable from the solar cell panels to the inverters and 25 kilometres of cable in the ground. RAH would also lay ten kilometres of high-voltage cable.

Heavy rain fell during the construction period and the contractors had to work in mud up to their knees but the deadline was met. On 23 December, the solar cells were connected to the grid, so the owners are now guaranteed the full 102 øre/kWh.

For RAH, the solar cell park was special because of its size and the fact that a large number of metering points have been installed close together. There has been one customer, but 36 connection points with settlements through Energinet.dk's DataHub. Going forward, RAH Net will own, operate and maintain the grid up to the measuring points, just as the RAH Group has become the owner of one of the wind turbines.

Visitor centre with a view

"We thoroughly enjoy our common showroom where we, being the engineering geeks that we are, can hold meetings with a view to the wind farm and solar park. The building will also be used by the municipality, which has just welcomed a team of Japanese visitors and hosted Vestas seminars", says Per Nielsen.

The consumption of electricity in RAH's supply area is almost 60,000 MWh per year. In the last two years, local production of electricity from wind turbines, solar cells and CHP plants has been approx. 90,000 MWh per year, so since 2014 the RAH area has been an "exporter" of green power.

More green electricity is on the way, which requires RAH to continue investing heavily in cables and components.

FACTS ABOUT
WIND AND SOLAR

Wind power (onshore/offshore) covers the equivalent of over 42 per cent of electricity consumption in Denmark. Denmark also has almost 100,000 solar cell systems with a total capacity of almost 800 MW. They account for approx. two per cent of consumption.

Just east of Ringkøbing in western Denmark, private investors have installed 72 MW of wind energy and 15.2 MW of solar cells. Photo: Danish Energy Association.

Langeland cracks the green code

Wind turbines, CHP and solar cells cover the equivalent of 177 per cent of electricity consumption on Langeland. Very few people know the positive energy story that includes the childhood home of the father of electromagnetism: H.C. Ørsted.

In Denmark, wind power supplies the equivalent of approx. 40 per cent of annual electricity consumption, but coverage locally can be much higher. Langeland is one of the islands which is showing the world that renewable energy is easier to integrate into the electricity system than expected.

"The wind turbines on Langeland cover 164 per cent of consumption, and if we include the electricity produced by the CHP plant in Rudkøbing and the solar cells, green electricity production rises to the equivalent of 177 per cent", says director Kim Henning Hansen of Langelands Elforsyning.

Years ago he was involved in a series of working groups under the Danish Energy Association. Engineers would estimate how many wind turbines there was room for in the Danish electricity system. At the beginning everyone was unfamiliar with the new technology, but...

"On Langeland we were concerned, but our worries have been proven baseless", says the director, considering the investments required in cables and grid expansion.

Need to be better at branding

Langeland has approx. 12,500 inhabitants, so there are roughly three times as many residents here as on Samsø. The island of Samsø is known around the world for its extremely high share of renewable energy – a fact that is partly due to large parts of the local community being engaged, and that director Søren Hermansen of the Samsø Energy Academy is able to sell this great story both nationally and internationally.

Kim Henning Hansen states that in the future Langeland must be better at branding itself:

"We do not use our green profile enough. We have a good story, but we need to learn to communicate it better", he says.

Good advice from former residents

On this long island in the south Funen archipelago, there is around 44 MW of wind energy, 8 MW of biomass-based CHP and 2 MW of solar cells. With coverage of 177 per cent of green electricity, Langeland surpasses most islands, so the residents here have a strong technical story to tell. As an extra twist in the tale, the father of electromagnetism, Hans Christian Ørsted (1777-1851), was born in the island's old pharmacy.

"Yes, Langeland must show its pride and become better at selling the island's many unique features in art and culture, nature and technology", says Helle Kastrupsen, born and bred on Langeland but who has since moved away and is now director of Montagebureauet, a graphic design office in Copenhagen.

Hans Christian Ørsted was born on 14 August 1777 in Rudkøbing on the island of Langeland. He was a physicist, chemist and pharmacist – and a close friend of the author H.C. Andersen. H.C. Ørsted is often described as the man behind the discovery of electromagnetism in 1820. Illustration: Langelands Museum

One idea, she suggests, could be - as they did on Samsø and Bornholm - for the islands leaders to collaborate and develop a common history and common vision.

"Langeland has many creative resources and can build on the fact that every year more than 25,000 people come to music festivals on the island", says Helle Kastrupsen.

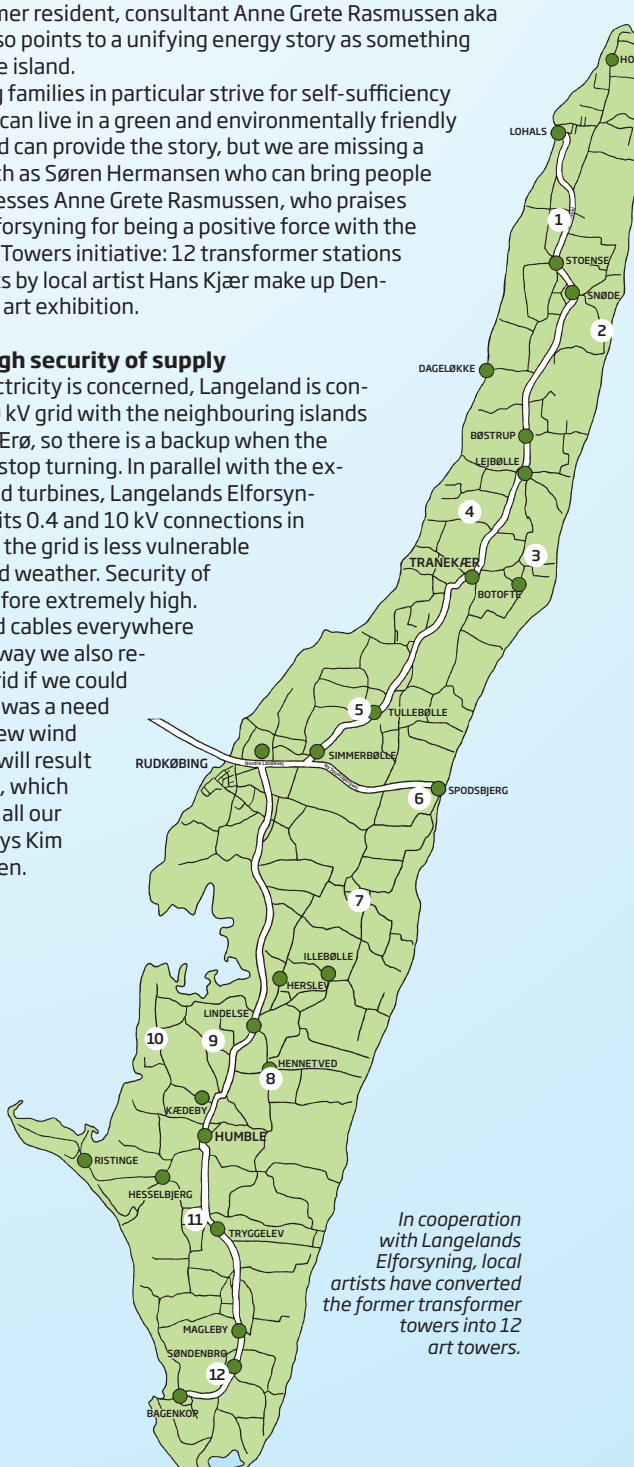
Another former resident, consultant Anne Grete Rasmussen aka FruGrøn.dk, also points to a unifying energy story as something that can lift the island.

"Many young families in particular strive for self-sufficiency in energy, and can live in a green and environmentally friendly way. Langeland can provide the story, but we are missing a key person such as Søren Hermansen who can bring people together", assesses Anne Grete Rasmussen, who praises Langelands Elforsyning for being a positive force with the Langeland Art Towers initiative: 12 transformer stations including works by local artist Hans Kjær make up Denmark's longest art exhibition.

Extremely high security of supply

As far as electricity is concerned, Langeland is connected by a 60 kV grid with the neighbouring islands of Funen and Ærø, so there is a backup when the wind turbines stop turning. In parallel with the expansion of wind turbines, Langelands Elforsyning has laid all its 0.4 and 10 kV connections in the ground, so the grid is less vulnerable to the wind and weather. Security of supply is therefore extremely high.

"We have laid cables everywhere and along the way we also reinforced the grid if we could see that there was a need for it to host new wind turbines. This will result in fewer faults, which is a benefit for all our customers", says Kim Henning Hansen.



In cooperation with Langelands Elforsyning, local artists have converted the former transformer towers into 12 art towers.

DSOs supply infrastructure for infrastructure

Electricity replaces diesel on the Aarhus Light Rail. Three DSOs ensure power for the new trains.

Railways, light rails, metro systems, superhospitals... around the world money is being invested in spectacular infrastructure projects and every time, DSOs are involved.

Meet electrical engineer Søren Damkjær Møller of DSO Dinel (formerly Aura El-Net) on the outskirts of Aarhus.

As a project manager he is responsible for ensuring that electricity will be available on one part of the 110 kilometre long Aarhus Light Rail.

"We are in the process of building six converter stations each with two connections to the light rail system. The light rail must have power and backup, and the trains must never stop running so we have redundant supplies", says Søren Møller, while he shows us around the train line from Viby on the outskirts of Aarhus down towards Odder.

Along the Aarhus-Odder line, the light rail will run on the tracks where until recently there were diesel-powered trains. 12 km of new tracks will be laid in Aarhus so that the university, hospital and Lisbjerg district can be served by the light rail, which meets the old "diesel route" to Grenaa just north of Denmark's second largest city.

30 converter stations

In total, the three DSOs involved – Dinel, NRGi Net and EnergiMidt Net – will establish 30 converter stations for Stage 1 of the light rail project. These stations will convert 10 kV AC from the grid to 750 V DC traction power.

Søren Møller unlocks one of the doors on the grey and white building called Train Power Supply 6 (TPS 6) in Viby:

"The converter stations are absolutely crucial. It is here at these supply points that the grid meets the light rail", says Søren Møller, pointing out the clamps that mark the boundary between "them and us".

Dinel works closely with the other DSOs to supply infrastructure for the light rail so that it will be as easy as possible for the mainly Italian contractors to complete their work before the deadline. The light rail must enter into service in May 2017.

Ready to test the trains

TPS 6 is ready and masts have been erected between Viby and Rosenhøj. Furthermore, electricity supply to TPS 6 has been upgraded so the first conditions for the service trial are now on track. In addition to TPS 6, Dinel has replaced an old 10 kV connection cabinet with a new one which can be monitored and controlled remotely from a control room in Odder, or "back at my house when I am on duty outside normal business hours", as Søren Møller puts it.

Further south at the train station in Tranbjerg, they are preparing to erect the masts which will provide traction power to the trains. Heavy concrete foundations must be hammered down into the ground using a mast rig before the masts themselves can be installed (there are 3,000 of these across the whole of the light rail network).

Dinel is not involved in this part of the project, but the DSO has cleared a piece of land and is therefore ready to build the TPS 5 converter station and connect it to the grid by laying a 130 metre long cable under the tracks.

13 km of cables

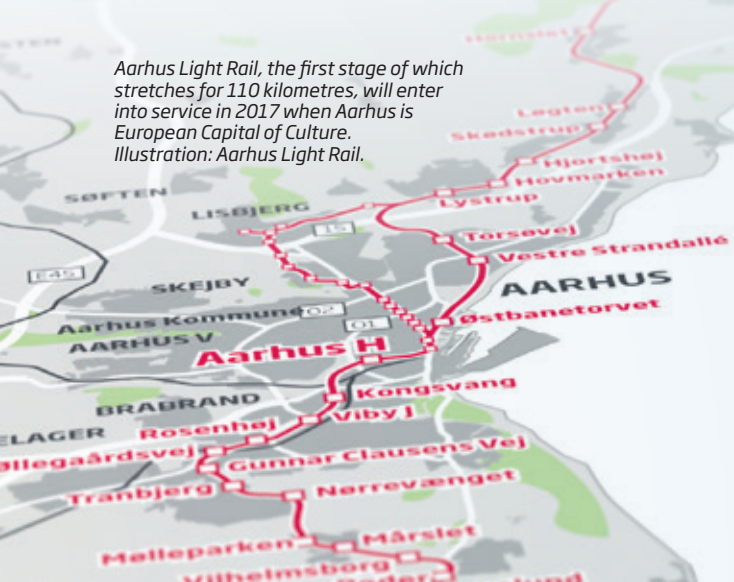
In order to meet the high demands for quality, Dinel has purchased 13 km of PEX cables for the light rail – 4.7 km of which has already been laid at Mårslet in connection with the TPS 4 supply point. At the same time, the old and paper insulated cables were removed.

"The grid improvements at Mårslet are taking place both for the light rail and to improve reliably of supply to the town, which has grown significantly over the last few years", says Søren Møller.

We are approaching Odder and can see signs of light rail activity spread across the countryside. Søren Møller explains that before the excavators got to work and the cables were rolled out, Dinel thoroughly tested a variety of solutions using the Net-Bas calculation and simulation tool. For Dinel, it is important that the light rail project does not adversely affect the reliability of supply.

"We will definitely be able to supply the power that the light rail needs without ignoring our other customers", states Søren Møller at the station in Odder, where the Train Power Supply 1 converter station is ready to be installed.

The city of Odense is also planning to install a light rail system, so Søren Møller is in discussion with DSO-colleagues from Energi Fyn Net to share experiences.



Aarhus Light Rail, the first stage of which stretches for 110 kilometres, will enter into service in 2017 when Aarhus is European Capital of Culture. Illustration: Aarhus Light Rail.

Electrical engineer Søren Møller of DSO Dinel unlocks one of the doors on the grey and white Train Power Supply 6 in Viby. Dinel will establish six converter stations that can transform 10 kV AC to 750 V DC. Photo: Danish Energy Association.

Frederiksberg Forsyning has purchased ten Nissan e-NV200 vans for its fleet of service vehicles. Photo: Frederiksberg Forsyning

While the electric vehicles are in the garage, they can supply power to the grid based on the parameters that Frederiksberg Forsyning agreed with Nuvve, whose software controls and visualises what is happening.

Electric vehicles sell power to the grid

Electric vehicle fleet supplies power to the grid: Japanese electric delivery vans, Italian charging equipment and American IT make Vehicle-to-Grid come together in a Danish project with global ambitions. Since September 2016, the world's first commercial V2G pilot project has supplied frequency reserves to the grid.

Think of a future with millions of batteries charging up with power FROM the grid – and later supplying power TO the grid when the electricity system needs it.

This future is moving closer, particularly thanks to a project in Copenhagen where the company Frederiksberg Forsyning has signed the world's first commercial contract to supply Vehicle-to-Grid (V2G) services.

"After some teething troubles, the technology is working really well and we are now in full swing selling frequency reserves to the electricity system. We do still have some tax and tariff challenges that we need to resolve with the authorities. This is new for all of us", says operations manager Martin Messer Thomsen of the IT company Nuvve, whose software optimises the purchase and sale of power to the grid.

Frederiksberg Forsyning supplies gas, water, district cooling and district heating to the residents of Frederiksberg municipality, as well as draining rain water and sewage from the area. Frederiksberg Forsyning has a fleet of vehicles to provide services in the municipality – including ten electric Nissan e-NV200 delivery vans.

These vans "fill up" on electricity from specially produced charging equipment supplied by the Italian energy company Enel. The charging equipment is equipped with an IT platform from Nuvve.

Evening, night and weekend

While the electric vehicles are kept in the garage in the evening, overnight and weekend, the electricity system can draw power from the ten batteries which have a total output of 100 kW. This is possible because Neas Energy, as a balancing authority, contributes to the market for frequency reserves.

"We are experiencing huge interest in this idea and expect to have a total of 40 electric vehicles connected to the system during the first quarter of 2017. Economically it is interesting for fleet owners to see their vehicles as assets – even when they are stationary", says Martin Messer Thomsen.

However, it is still too early to say how much of an income the sale of frequency reserves and other services to the grid may generate. Based on the EU funded Nikola project, researchers at the Technical University of Denmark have previously calculated that it may bring in approx. DKK 10,000 per year per vehicle. To this should be added the value of CO_2 savings and the cleaner air that a conversion from diesel to electric vehicles involves.

Take a look at the UK

The cooperation between Nissan, Enel and Nuvve will continue with six vehicles for Bornholm municipality and seven for the outdoor advertising company AFA JCDecaux. Nissan, Enel and Nuvve are looking at the Netherlands and the UK as the next markets:

"The UK could be the big market for V2G. The grid is not as strong as in Denmark and Germany, and the UK need to integrate much more renewable energy. This provides a significant demand for frequency reserves, so we are experiencing a great deal of interest in our solution", says Morten Messer Thomsen.

Nissan has placed itself at the forefront of the global conversion to electric vehicles with the LEAF and the e-NV200. They see the charging/discharging of electric vehicles as part of the response to global challenges such as air pollution and climate change, as well as the inclusion of fluctuating power from solar cells and wind turbines.

All newer electric vehicles from Nissan can supply power to the grid without undergoing technical modifications and come with a standard 8 year guarantee. The condition for being bi-directional is that vehicles are fitted with the new CHAdeMO connector so the new electric vehicles from Mitsubishi and Toyota are also V2G ready.

Electricians must register batteries

The number of batteries connected to the Danish grid is increasing, but nobody has an overview of where the batteries are, how big they are and what power they can deliver. This cannot continue in the long run, so during 2017 electricians will be obliged to register new installations so the DSOs can follow the development.

"More and more batteries are being installed in connection with solar cell systems and electric vehicles. In many of the batteries, the current will be able to flow both ways, which could be very important when it comes to dimensioning and managing the distribution grid", civil engineer Louise Carina Jensen of the industry's Danish Energy Association points out.

"It is essential that consumption data from the electricity meters is made available to market players under security and equitably. The DSOs are responsible for providing this data as neutral market facilitators. In addition, the smart meters can deliver technical data that will be essential for the intelligent operation and expansion of grids. For the DSOs to be able to optimise the local grid, it is essential that they have direct access to download exactly the data they need from the individual metering points"

Anders Stouge, Deputy Director General, Danish Energy Association

Digital rewards

More and more energy companies around the world 1) meter and collect data, 2) visualise and analyse and 3) streamline their energy system and provide customers with new choices.

The quantity of data is currently growing exponentially and, according to the World Economic Forum (WEF), this digitisation can deliver significant technical and financial returns for the energy industry and its customers.

An analysis carried out by the WEF in cooperation with consultancy company Accenture shows that this trend towards digitisation could yield returns of 3.3 trillion dollars in the OECD countries between 2016-2025. An astronomical amount over the next ten years.

But where do we find these returns?

According to the World Economic Forum, the potential financial advantages are spread across the entire value chain.

The value for the electricity sector is valued at 1.3 trillion dollars across production-markets/trade-transmission-distribution-meters-customers.

"The greatest returns are at the end of the value chain in the distribution grids and with customers, but the returns that are easiest to realise are found in production and in the transmission grid. These have good opportunities to exploit digital technologies – without new policies – to streamline their operations," says the energy technology manager Bosco Astarloa of the WEF.

For electricity customers, it can be a very good idea to monitor how electricity consumption evolves.

Over half of all Danish homes have a remotely read electricity meter, so these families avoid having to manually read and send data to their electricity supplier.

By 2020, all meters in Denmark will be read remotely, and consumption data will flow fully automatically from all homes and businesses to the country's DSOs and electricity suppliers.

The World Economic Forum points to digitisation as one of the three disruptive trends which are currently affecting the energy industry. Decarbonisation and decentralisation are the other two.

"Digitisation is happening faster than you think. We must be prepared," Bosco Astarloa points out, based of interviews with 35 CEOs from the electricity sector.

Globally, there are already over 20 billion devices now connected to the internet – including many electricity meters and sensors in homes, industry and transformer stations. By 2020, it is estimated that there will be 7.4 billion devices on the net across the value chain just in the electricity industry.

The World Economic Forum has no doubt that this trend towards "The Internet of Me" will continue and provide the energy industry with entirely new opportunities, e.g. optimised operation of the electricity grid, intelligent control of energy consumption, home automation and interaction with customers.

The potential efficiency gains will flow like millions of water droplets that collect to form a river. Bosco Astarloa points out that digitisation and the new customer focus that accompanies it will change the electricity industry completely.

"We are witnesses to a change in value creation from central, conventional production towards the end of the value chain," he notes, pointing to American states such as California and New York as front runners in issuing policies that can support smart grid initiatives.

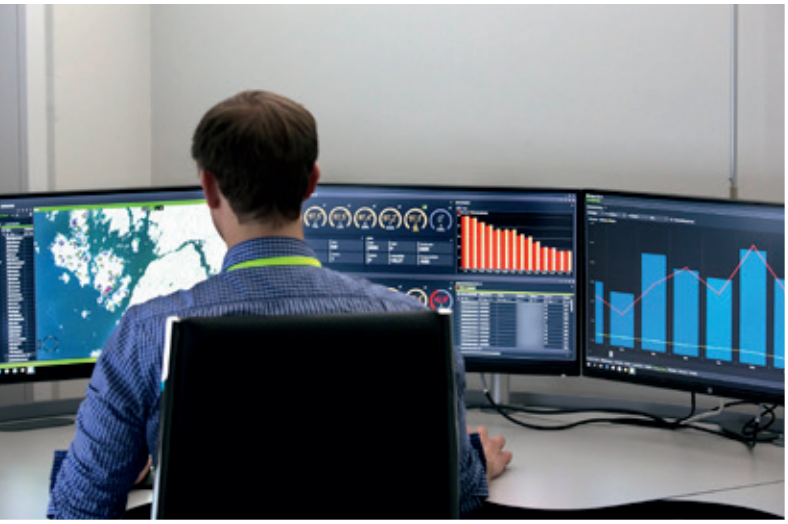
Required: Smart Meters for electricity, water and heating

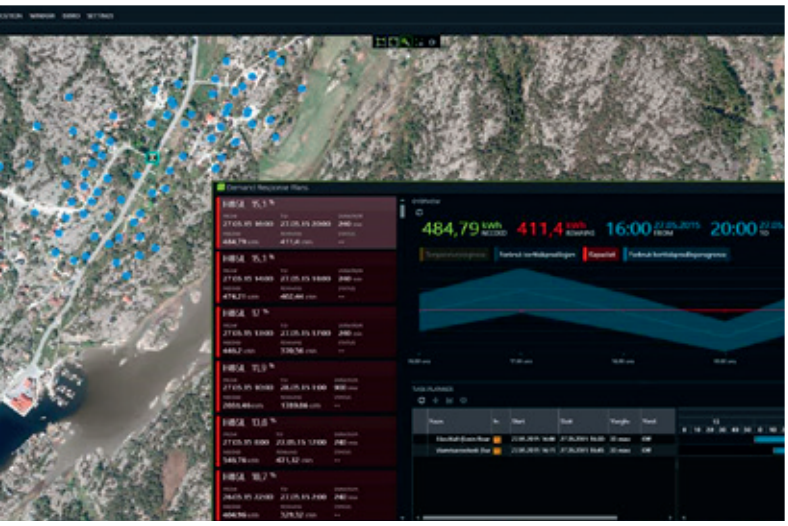
With the roll-out of digital meters, the electricity sector and other utilities will have an immense amount of data available.

The data must be exploited, says Helle Juhler-Verdoner, managing director of the Danish Intelligent Energy Alliance, a partnership of utility companies and suppliers:

"Digitisation of the utility sectors is in full swing. The remotely read meters for electricity, heating and water are an essential precondition for digitisation, which will create many new opportunities to make it easier, greener and cheaper to supply products to customers."

"By combining data from the infrastructure with new business models, we will be able to create value for customers and the companies involved," she says.





Photos: eSmart Systems

Visualisation of data reveals the big picture

DSOs and other electricity suppliers can use images to understand the large amount of data gathered by smart meters.

Click, click, click.

A few clicks of a mouse and up pops a map on the screen in the DSO's control room. The map shows where there is consumption and production, where transformer stations are located – and where any supply interruptions have occurred.

"By using our analysis platform and the many different visualisation options available, the DSO can organise their data and strengthen their financial position," says country manager John Haar, eSmart Systems, Denmark.

eSmart Systems is one of the companies that is trying to help DSOs and other suppliers create value out of the large amount of data from smart meters, regardless of whether the data is from electricity, water, heating or gas – or a combination of all three.

Current data can, for example, be combined with historical data and measurements taken from other parts of the distribution grids – and even images captured by drones.

"Utilities can quickly repair damage and will generally be able to provide a better service to customers. They can also get an overview of the grid status and thus be better placed to plan investments. If the same fault has occurred many times before, the fault can be predicted through machine learning – and this may reveal that it is now time to invest in a new cable or a new transformer station," John Haar points out, mentioning that instead of new investments, the system can act before a crisis occurs by controlling underfloor heating, hot water tanks or heat pumps.

According to John Haar, the system can also promote the interaction between DSOs, electricity suppliers and end customers. Data can be collected in an app and it will be possible to download useful information from social media such as Twitter and Facebook. Specific words (e.g. "Oh no, the power has gone off") can be captured by a filter and an alarm sent to the energy company.

Every hour, data is optimising DSOs

With billions of data values transmitted from smart meters, located both at customers and within the grid, the DSOs are given new opportunities to trim their networks and make them ready for more renewable energy.

Improving voltage quality

Data from remotely read meters can be used by DSOs to improve voltage quality in the grid. The companies have an obligation to supply a voltage of 230 Volts plus/minus 10 per cent, but historically they have found it difficult to know whether they fulfilled this obligation. With smarter meters, DSOs can document whether or not the voltage is as it should be. Fluctuations in voltage can affect and ultimately destroy vulnerable devices in homes and businesses, so there could be a lot of money at stake for both DSOs and customers.

Detection of power theft

Smart meters can detect if a customer's consumption suddenly increases sharply. There may be a good explanation, but it could also be a case of power theft. The Danish Energy Association estimates that electricity worth DKK 50 million is stolen every year in Denmark. Some of the larger power thefts are perpetrated by indoor cannabis farms and there are examples of them using power worth more than DKK 250,000 over four months.

Reducing investment costs with smart meter data

Syd Energi Net will soon have 300,000 remotely read meters. The company expects to optimise investments, operations and maintenance when data analysis becomes an integrated part of the corporate culture.

Over the last ten years, DSO Syd Energi Net has primarily used data from its 275,000 remotely read meters to correctly bill electricity consumption. The company is now getting ready for the next phase: Using meter data to target investments as well as for operations and maintenance.

Daniel Skovsbo Erichsen, director of asset management and grid strategy at Syd Energi Net, points out that DSOs have an obligation to allocate their budget responsibly.

"We have a great social obligation to invest in the best possible way. At the same time, we must be able to manage the green transition that is now really gathering pace. More is happening on the distribution network now than in the previous 30 years," says Daniel Skovsbo Erichsen.

Meter data is now being used to detect power thefts, for example, but the really big financial returns will accrue when the DSO can postpone investment in new cables, reduce peaks in consumption or expand the grid in a more optimal way.

"We are continually optimising and expect to be able to save investments, for example through better exploitation of the huge amount of meter data that we have collected over the last ten years," says Daniel Skovsbo Erichsen.

Syd Energi Net was one of the first Danish DSOs to install remotely read meters. There is no urgent requirement to replace the first generation of meters, but in the next few years, 45,000 meters will be installed at the former customers of the Nordjysk Elnet company, which has been merged into the SE Group. Like other DSOs, Syd Energi Net is also busy making the new Supplier-centric model more operational.

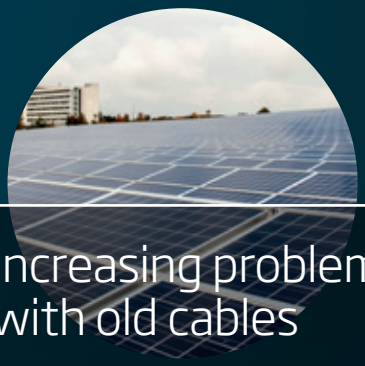
"We need to think carefully when we invest in the next few years. We already have wind turbines, solar cells, electric vehicles and heat pumps for detached houses in our system, but technological developments and the price of these technologies mean that a great deal may happen in the coming years," says Daniel Skovsbo Erichsen.

He mentions the combination of solar cells and batteries, isolated batteries, large heat pumps in district heating plants and electric transport as some of the technologies that could have a breakthrough and increase the need for investment in the grid.

"In the old days, not so very long ago, we got all our power from a few central power plants. Power now flows into and out of all parts of the network, so we have a very exciting world to look forward to," he says.

Syd Energi Net has already collected quite a lot of data and they now need to look at the patterns – and to change the company culture so that employees all work together when considering a new method.

"Our goal is to increase capacity in line with demand and to ensure stability of the grid at an affordable price. We will not build a large system, but keep it reasonably simple and then build along the way, as we grow wiser," says Daniel Skovsbo Erichsen.



"Member States shall ensure the implementation of intelligent metering systems that shall enable the active participation of consumers in the electricity supply market (...) Where roll-out of smart meters has a positive business case, at least 80 % of consumers shall be equipped with intelligent metering systems by 2020"

Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009

Increasing problems with old cables

When cables have been in the ground for 30-35 years the number of faults begins to increase, according to the report "Failure rate of 10-20 kV cables" from the Danish Energy Association.

"From 1965 until the end of the 1970s, the DSOs laid 10,000-12,000 kilometres of paper and oil insulated cables, especially in the larger cities. The cables are generally in good condition, but more faults occur as they get older. The failure rate increases significantly after 30 years of operation," notes Jens Zoëga Hansen, a civil engineer at the Danish Energy Association.

Most DSOs repair the old so-called APB cables when they fall apart. The alternative is to replace them with more modern plastic cables (PEX). There are currently over 40,000 kilometres of plastic cables.

"The choice is between maintaining the old cables and investing in new ones – pure asset management in other words," says Jens Zoëga Hansen.

The Danish Energy Association is experiencing increasing interest for asset management among the DSOs – the smart meters are expected to be a valuable tool here. The Danish Energy Association regularly holds courses on the potential benefits of asset management as a management tool, and the participants are given tips on how they can get started.

How to replace 1 million smart meters

Radius is investing approx. two billion DKK in remotely read electricity meters. They are supposed to make it easier to be an electricity customer and to increase competition between suppliers.

One million households are due to change electricity meter in the largest ever operation of its kind in Denmark. The DSO Radius is behind the project.

"We need to reach as many people as possible. Approx. two thirds of the meters are located within people's homes in cellars, utility rooms or cupboards in apartments. A third of the meters are located outside, but we still need the consent of the customer to enter their property and to change the meter", says technical director Anders Vikkelsø of Radius.

The Danish Parliament has decided that all electricity customers in Denmark should have remotely read meters by 2020. Nationally, more than 50 per cent of customers already have digital remotely read meters. At Radius, only 3 per cent of their 1 million customers have smart meters. These are large customers with a consumption of over 100,000 kWh per year and home owners with solar cells on their roof.

Now the rest of Radius' approx. 970,000 customers will also receive a new electricity meter. A total of one million meters will be replaced.

Two major tenders

Visiting so many addresses requires thorough preparation and lots of communication. Radius began the preliminary analyses in 2012 and then started the project groups that were to prepare the relatively large EU tenders in order to implement the project, which has a budget of approx. two billion DKK.

In the spring of 2015, metering and IT company Kamstrup was awarded the order for one million meters and the task of installing the many meters. The underlying IT system, the so-called Meter Data Management System, which is able to handle 24 million meter readings per day from the hourly billed meters, is supplied by Landis+Gyr.

In May 2015, Radius and the suppliers were able to begin the actual project work and in December 2016, the first new meter was installed for a customer in Albertslund on the outskirts of Copenhagen – as part of a three month pilot project with 16,000 households.

"From the day the customer gets a new meter it is read remotely, but we are starting slowly at first to catch any problems that may occur. The IT system must work, so the key word at the start of the project is test, test", says Anders Vikkelsø.

Correct data for the customers' electricity consumption is crucial to ensure that electricity suppliers can issue the correct bills to their customers. "As a market-neutral DSO, Radius therefore takes the task very seriously", states Anders Vikkelsø. The meters shall record consumption (and possible production) then send the data via a central DataHub at Energinet.dk for validation and subsequent use by the electricity supply companies.

"The meters communicate using radio signals so we do not use the internet", says Anders Vikkelsø, stating that IT security is a high priority.

Many special cases

The first wave of meters has been planned, so Radius and Kamstrup will gain experience in servicing many different types of customers... so there is a good distribution between detached houses and apartments and between scattered and dense housing.

All customers first receive a letter from Radius explaining what is going to happen – then a letter from Kamstrup about when the change will be carried out. Customers can alter the time by contacting Kamstrup, who expect the replacement to take half an hour and normally not require an interruption to the power supply.

The letters are written in Danish, but not all the letters will arrive, not all customers read their post and not all electricity consumers in the multicultural cities understand Danish. Radius and Kamstrup are therefore curious about how many doors will be opened to them.

"We are going to see many special cases, so it is good that we can rehearse for them now. We have of course planned with Kamstrup how we will manage to visit all our customers. The roll-out itself takes place from 1 May 2017 to the end of 2019. During this period, approx. 120 engineers aim to change 1,500 meters every day, six days a week", says Anders Vikkelsø of Radius, part of the DONG Energy Group.

Meters with many functions

Remotely read electricity meters are just one part of the green transition. Denmark's goal is to be independent of fossil fuels by 2050, which requires more electricity to be produced from wind turbines and other sustainable sources. Wind turbines already supply the equivalent of approx. 40 per cent of electricity consumption, but when penetration reaches 60-70 per cent there may need to be more flexible electricity consumption to balance production.

The new meters make it possible to bill electricity on a 15-minutes basis, as the electricity suppliers can use the large amount of data to visualise customer consumption.

"The new meters will make it easier to be an electricity customer. They provide easy access to current readings and statements via your electricity supplier or on the website eloverblik.dk. So it will be easier to follow and manage your consumption – thus saving you money by using less electricity or by moving parts of your consumption to the times when electricity is cheap", says Anders Vikkelsø.

Specifically, customers will no longer have to read their electricity meter once a year – or when they change address or their electricity supplier. When remote reading is enabled, this happens automatically. If an electricity supplier asks to disconnect a customer, this can also be performed remotely.

"The meters have many features and we look forward to exploring the possibilities over the coming years. My hope is that during 2017 we can also offer hourly billing with differentiated tariffs to small customers", says Anders Vikkelsø, pointing out that these plans depend on whether the industry and authorities are able to put the necessary policies in place.

"Our biggest task yet"

1

Kamstrup will produce one million meters, coordinate logistics for Denmark's largest roll-out, ensure interaction with Radius' IT system and maintain operations until 2034.

Knock-knock-knock!

Within an agreed time window of four hours, two meter engineers from Radius/Kamstrup knock on an apartment door in the centre of Copenhagen. They are there to replace the electricity meter and are shown into the narrow pantry where the household's metering device is located.

In the course of the next 20 minutes, they take pictures of the old meter with a mobile phone, read the consumption, remove the meter – before installing a new one, which they also photograph. Before they say goodbye, they check that the new meter works and hand over a small pamphlet with information.

From now until the end of 2019, approx. 120 meter engineers will replace a million electricity meters in Copenhagen and the surrounding area. The task of replacing the meters is being carried by the metering and IT company Kamstrup on behalf of DSO Radius, who have outsourced a major part of the project.

"It is our biggest task yet and one of the largest roll-outs in Scandinavia. To produce a million meters is a big job in itself, but this is also about logistics, interaction with the entire IT system and operations until 2034. We take responsibility for ensuring that the solution also works in the long run," says senior vice president Henrik Mørck Mogensen of Kamstrup.

The meters will be produced at Kamstrup's factory in Stilling, almost 300 km from the Danish capital. The factory is automated to such an extent that even though electronics are involved, it makes better sense to produce it in Denmark than in China.

Fresh from the factory

The ready-made meters will be collected by the company Solar, who will deliver them to the Copenhagen region via an intermediate depot in Vejen. In the dead of night, the meters will be loaded onto service vehicles which will go out from the early hours to deliver the meters to customers. The white delivery vehicles display the names Radius and Kamstrup, but the meter engineers come from the subcontractors Eltel Networks and Nordic Meter Replacement.

Are Kamstrup anxious and uncertain about this task, or are they calm and relaxed about it?

"We have over ten years of experience with roll-outs and digitisation in the electricity, water and heating sectors, but we are approaching this huge task with caution. We have prepared for over 1½ years and have a good dialogue with Radius and our partners," says Henrik Mørck Mogensen.

A pilot phase with 16,000 households will provide them with initial experiences before the roll-out begins in earnest.

"We are seeing that customers are being nice to us, but they are not always at home as agreed. Copenhagen is a big city which also provides its own specific challenges. For example, it may be difficult for our people to find a parking space near the property they are visiting," says Henrik Mørck Mogensen.

Software can be updated

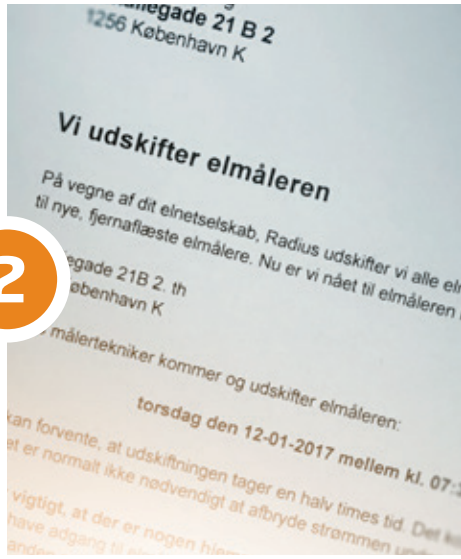
The meters can be read remotely from the moment they are installed. The key here is that data can be used to bill electricity consumption.

Meter technology is developing all the time. Will the same type of meters be installed at the start of the roll-out as at the end?

"We invest a great deal in research and development, but the basic platform will be the same throughout the project. There will be continuous improvements made to our software with new services and increased security, but right now at the start we are focusing on the roll-out and billing. Looking to the future, we must of course be ready to cope with differentiated tariffs and shorter billing frequencies if we decide to introduce it," says Henrik Mørck Mogensen.

Kamstrup is receiving considerable international interest in the project. All electricity customers in the EU – as far as it makes economic sense – must have remotely read electricity meters installed. In Sweden this is already the case, but many of the Swedish meters are technologically obsolete, so the DSOs there are considering investing in a new generation of meters. Henrik Mørck Mogensen also reports significant curiosity for the Radius project, in particular from Austria and Belgium.

And what about the old meter from Copenhagen? Perhaps it will get to stay in a "meter hotel". Radius expects to store ten per cent of the meters at a warehouse in Ballerup. There is room here for up to 100,000 meters. Selected meters will be stored for three years in the event that there should be any doubt about the correct meter reading.



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DSOs in a joint effort to optimise

Western Danish distribution companies with 1.25 million end customers are cooperating under the Net-Sam SCADA consortium on optimum operations and planning, so that production from wind turbines can flow along the shortest routes.

Energy equivalent to approx. seven per cent of the power produced in Denmark is lost during transmission to customers through wires, cables and transformer stations. A number of western Danish DSOs are trying to reduce this waste through the joint operating company Net-Sam SCADA and – by cooperating on operations and planning – to optimise their combined distribution system.

"Most of the wind turbines in Jutland are located in the west, while most of the consumption is in the east. So the goal is to find optimal routes through the grid and on to the customers. Together, we hope to improve operations and increase uptime", says director Claus Lund of Net-Sam SCADA.

When fully operational, Net-Sam SCADA will cover 1.25 million electricity customers, monitoring all levels of the network from 60 kV and lower. The system is modular, so there is room for more DSOs and other utilities such as heating, gas and water.

Top notch IT security

More and more communication in the energy sector takes place over the internet, but the companies behind Net-Sam SCADA will not compromise on IT security. Net-Sam SCADA makes use of several data centres, so "we can tolerate an interruption in one place and still continue to operate", as Claus Lund puts it.

"And no… our data does not reside in the cloud and is not transferred via the internet", Claus Lund states firmly.

Net-Sam SCADA itself has two employees and the company rents premises at the energy company NRGi. This has the benefit that they can test solutions and promptly get praise and criticism from their colleagues in the local control rooms. Following a tender process the IT platform, which can control and monitor everything from transformer stations, cables and overhead power lines to decentralised electricity production, is being supplied by the German company PSI.

"We have also hired people with specialist knowledge from PSI to be available for operations 24/7. So we have dedicated staff to ensure among other things, that IT security remains at the highest level", says Claus Lund.

The control and monitoring system is helping to pave the way for a more intelligent energy system. Most of the customers of the DSOs behind Net-Sam SCADA have remotely read electricity meters. In the coming years, more and more devices will be able to respond to price signals in the electricity market – just as commercial and industrial customers currently do.

"We believe that we are creating a system that is more up to date and future proof. We are already able to use forecasts and simulations to optimise power flows through the grid. This kind of thing will become even more necessary as we connect more wind turbines and solar cells to the grid", says Claus Lund, who estimates that investment in the new joint system is much cheaper than if the individual companies had invested money in their own solutions.

In eastern Denmark, SEAS-NVE has been using an older version of the IT platform from PSI for 8-10 years, to control and monitor its sprawling supply grid of 112 50/10 kV transformer stations.

"We have been extremely satisfied with the system and are now working on an upgrade", says grid director Henrik Wej Petersen of SEAS-NVE.

SEA-NVE has also increased its focus on security and Henrik Wej Petersen expects that the stricter requirements for securing data will be reflected in the new version.

Shared database of faults

Danish families and businesses have electricity in their power sockets 99.99 per cent of the time – but faults do occur. Net-Sam SCADA, SEAS-NVE and other DSOs report faults and interruptions in the grid to a shared database, ELFAS, and this statistical data is used by the Danish Energy Association to analyse which components have failed and what the cause could be.

"This knowledge can help us to investigate how to prevent future faults and when a specific type of component needs to be serviced or replaced. The new Net-Sam SCADA simplifies the reporting process to ELFAS significantly, and I expect that this will result in even higher quality data", says civil engineer Louise Carina Jensen of the Danish Energy Association.

The Supplier-Centric Model - one bill per customer

The technology behind the new electricity market works.

For the most part, the Supplier-Centric Model that was mandated by Parlament and introduced in Denmark on 1 April 2016 works as it should.

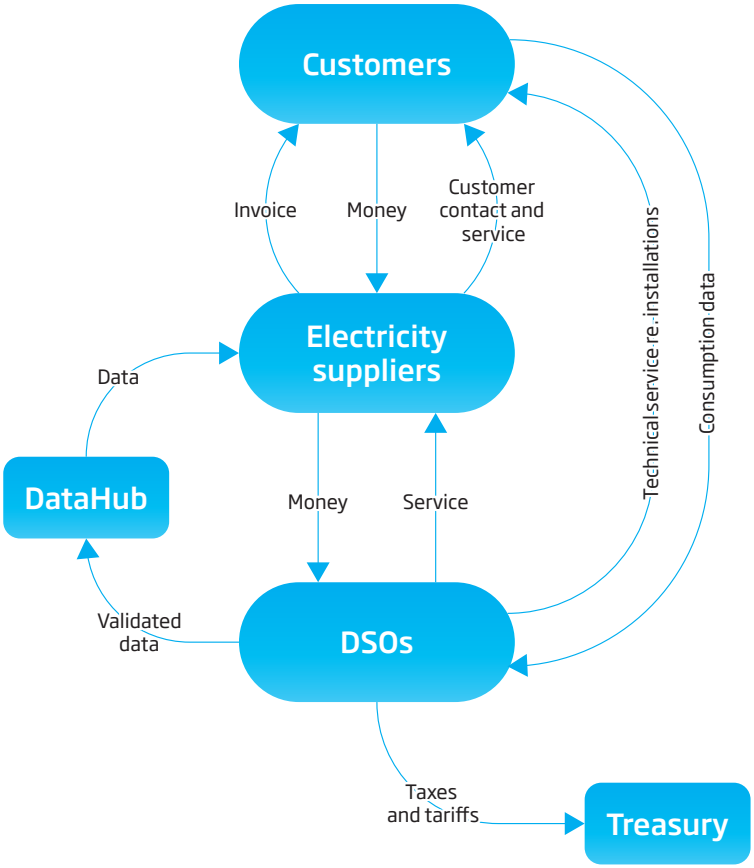
Meter data is collected from customers, validated by the DSOs and forwarded to a central DataHub. The electricity suppliers, who have contact with the customers, retrieve the data from the DataHub and issue bills to their customers.

The parties behind the Supplier-Centric Model continue to work on a series of improvements. For example, there is a desire to get more customers to provide demand response and to give market actors a better opportunity to use the data that is generated.

About half of Danish electricity consumption is billed hourly, which is the precondition to achieve more flexibility in the electricity system. Hourly billing for small customers is also on the way.

Over the next few years, the amount of data will grow substantially as the number of customers with smart meters increases. The roll out of more smart meters will increase the number of meter readings from 16 to 42 billion per year.

Consumers can download their own data from the website Eloverblik.dk or via their electricity supplier. Customers can also provide a digital signature, NemID, to allow energy efficiency consultants and brokers to access the data - and thus analyse opportunities to reduce electricity bills.



Switch electricity supplier in one minute!

"The Danish electricity market must make it easy for customers to switch electricity supplier - and it is easy", says managing director Morten Nissen Nielsen of electricity supply company Vindstød.dk.

"It only takes a minute", he says.

The assumption is that the customer has found the company and the product he or she would like to switch to. Then it just takes a few of mouse clicks to become a new customer of Vindstød.dk or another electricity supply company.

"Introduction of the Supplier-Centric Model has clearly been positive for end customers and strengthened competition in the market. Our strategy is to be a fully digitised energy company and we have invested a great deal in IT. Our success is proof that the market infrastructure works", says Morten Nissen Nielsen, and mentions that a number of the other approx. 60 supply companies in the Danish market are also using Vindstød.dk's IT platform.

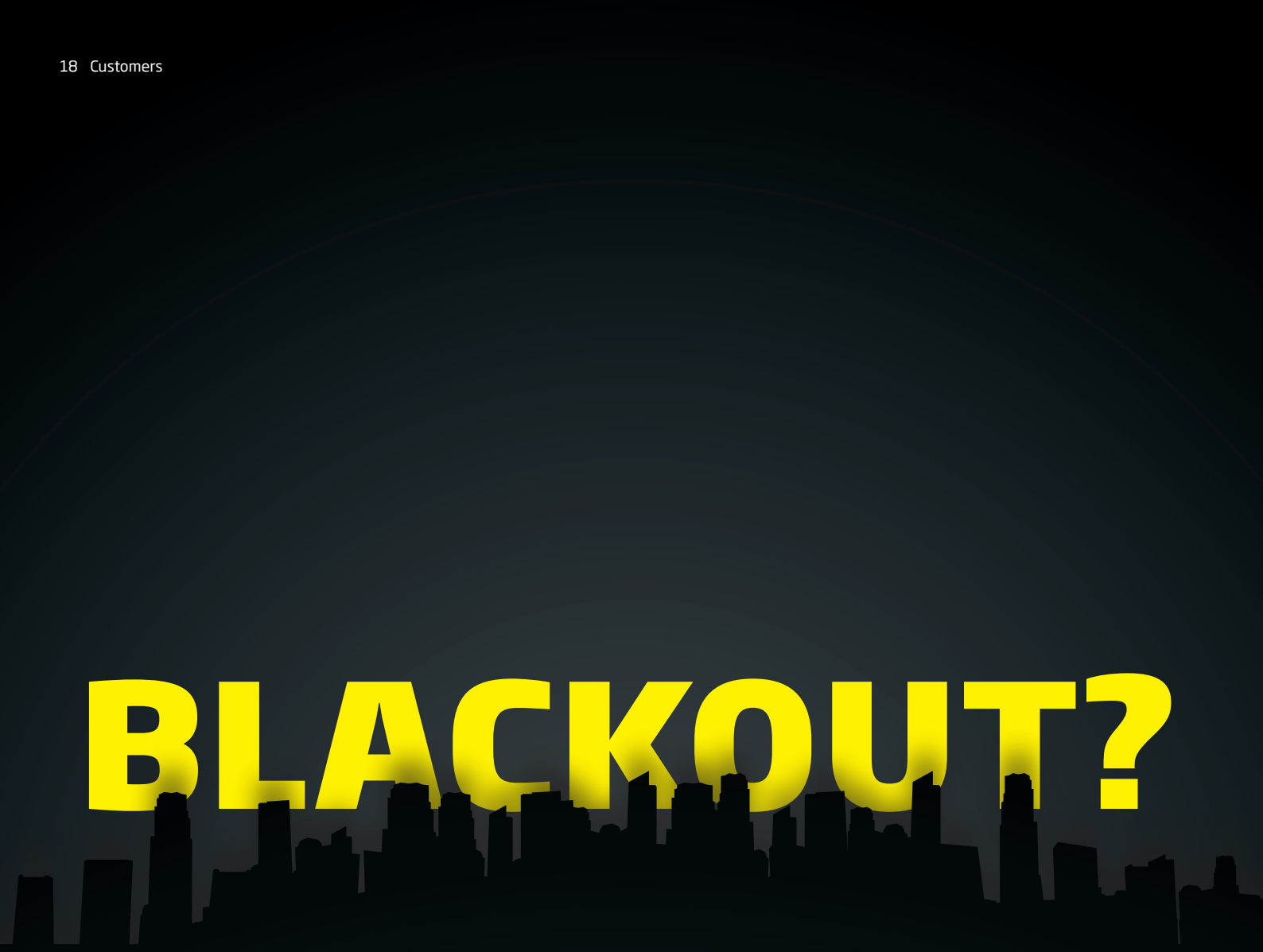
"We have created a small community where together we develop and finance IT development, even though we each have our own energy company. It is an expression of cooperation in a competitive market", the director explains.

Data from every electricity meter in the country flows from the DSOs via a central DataHub and out to the electricity supply companies, who have contact with the customers and bill them for their consumption. In addition, the DSOs make life easy for the electricity supply companies, for example with common standards and an IT platform for monitoring faults.

"The technical dialogue between DSOs, electricity supply companies and Energinet.dk works really well, and it is only very rarely that we experience a breakdown in communication via the DataHub. All in all we have a really good process", says Morten Nissen Nielsen of the innovative business Vindstød.dk, which has attracted investment from the Swedish energy group Vattenfall who has bought 70 per cent ownership of the company.

Vindstød.dk only sells power from Danish wind turbines to its customers.

Morten Nissen Nielsen, Vindstød.dk: Introduction of the Supplier-Centric model has clearly been positive for end customers and strengthened competition in the market.



Not here! Danish customers have electricity in their power sockets **99,99%** of the time

DSOs make it easy for electricity suppliers

All Danish electricity customers have a free choice of products from approx. 60 suppliers, and it is the suppliers who have virtually all customer contact and and issue a single bill (including charges for energy, grid tariffs, and taxes) to their regular domestic customers.

The DSOs are responsible for technical operations, and following the introduction of the Supplier-centric model in 2016, they ensure that the electricity suppliers can compete for customers on a level playing field.

A number of national agreements support the point that from now on, the DSOs are neutral facilitators in the market.

Special customers

For over 100 years electricity customers have drawn power FROM the grid, but with more and more solar cells on rooftops, more and more customers are also supplying power TO the grid. The solar cells can be combined with batteries, as future electric vehicles will also supply power to the grid for short periods – thus leading to complications for the DSOs. The Danish Energy Association is therefore holding talks with the TSO Energinet.dk on behalf of the DSOs about how they can harmonise the way these smart electricity customers can be connected to the grid.

Digital meters for all

Well over half of all Danish electricity customers have digital meters and as a result of an EU directive, the Danish Parliament decided that everyone must have a smart meter by 2020. The meters can be read every hour and allow the electricity suppliers to develop products that promote flexible electricity consumption for smaller electricity customers.

Tariff model

The Danish DSOs have different tariffs (øre/kWh), but the method used to calculate the tariffs has been harmonised with the "Tariff Model". This has made it easier for electricity suppliers to understand the tariffs and to service their customers.

The tariff model allows the DSOs to be able to offer tariffs that vary over 24 hours.

The DSOs are also in the process of harmonising the terminology for the services behind the various tariffs, just as they have harmonised the terms behind the fees that can be charged.

Platform for monitoring faults

Blackout! Every day has its small (and in rare cases larger) power interruptions. In order to make it easy for all active electricity supply companies to respond to calls from customers, the Danish Energy Association has set up a national IT information platform for power interruptions.

DSOs have a duty to report all unannounced high-voltage events to the platform. This is where they can also leave a message when power is back on. The DSOs also have the option of publishing planned interruptions and low-voltage events.

The electricity supply company OK, which has customers throughout the country, has put the national operations map on its website. The DSOs NOE Net and Dinel are examples of DSOs that shows the status of interruptions in the local area.

"The electricity supply companies can give their customers very precise information, so I hear from the DSOs that they are receiving fewer and fewer calls", says senior consultant Peter Kjær Hansen of the Danish Energy Association.

Common billing

An electricity supplier may have customers distributed over up to 60 DSOs who traditionally have billed in their own way. Common billing is on the way to make it easier for electricity supply companies to understand and manage the bills they receive from the DSOs.

Standard agreements

Electricity suppliers have contact with the customers, but what should they do if there is an interruption to supply, or if a customer is to be disconnected because of arrears? A lot of money is at stake between the different actors, but how should this money flow between the DSOs and the electricity supply companies? The answers to these and many more questions are described in a standard agreement between the DSOs and the electricity suppliers.

New names for group related companies

Some of the electricity supply companies in the Danish electricity market have their roots in the energy groups who constructed the grid over the last 100 years. These conglomerates are operated in a compartmentalised way and are functionally separate. Furthermore, there is a trend towards creating distinct brand identities for the DSOs. Denmark's largest energy company, DONG Energy, now operates a DSO which has been renamed Radius, while AURA Energi calls its DSO Dinel. In other cases, it is the group itself that has changed its name. For example, TREFOR El-net is now owned by EWII.

Electricity customers can switch supplier quickly and free of charge via the www.elpris.dk website. The customer enters their postal code and consumption level – then clicks on "Find prices" and a number of offers pops up. The customer chooses their new product (read the small print!), confirms and enters their personal details. Click "Register"... and the electricity supplier takes care of the rest. Photo: Thomas Steen Sørensen

Electric grid subjected to test and terror

Energy companies test technology and procedures in a joint emergency exercise. At DSO Eniig, everything takes place with total commitment and fresh points of view.

An accident rarely happens alone. On a chilly day in November, a number of Danish DSOs were affected by a power failure in Germany and a possible terrorist incident. Approx. 30 per cent of all customers in western Denmark were hit by blackouts.

... luckily it was just a rehursed exercise organised by the transmission and system operator (TSO) Energinet.dk and Jysk Netforum, which includes all Jutland-Funen DSOs with 60 kV installations. Eniig is one of these DSOs:

"We have quite a challenge because we are in the middle of a merger between two DSOs. We have decided to implement a single joint exercise, even though our IT systems do not yet run jointly", explains emergency coordinator Morten Eriksen of Eniig just before the exercise starts at 8:00.

Morten Eriksen has assembled his colleagues from the two "old" companies, EnergiMidt Net and HEF Net, for a joint briefing outside the Eniig control room in Aalborg. The control room itself on the other side of a closed door is manned and will not be affected.

Claus Holmgaard is monitoring operations during today's exercise. At his side is operator Michael Meldgaard. Their task is to ensure that communication with Energinet.dk functions according to the guidelines applicable to crisis situations – and that Eniig does what the company is asked to do... for example to disconnect customers if that becomes necessary.

Men of the right caliber

Around Holmgaard and Melgaard, a dozen men in their prime buzz around to observe, comment and learn from today's events.

"We are going to see a lot that works, and we are going to see a lot of challenges", says Jesper Bak-Jensen, manager of Eniig's grid department, shortly before the first communication from Energinet.dk comes in on a secure line: The grid telegraph, which delivers short, precise messages.

At 8:30 Energinet.dk informs us that the weather is cloudy with hardly any wind. The exercise is under way. The transmission grid functions as it should... and then it doesn't.

Suddenly there is a report of increased power and the mood becomes electric. Even if it is "just a game", the group takes the challenges very seriously. Holmgaard and Meldgaard immerse themselves in their computers and communicate with the outside world – while the others debate for dear life.

Eniig must respond in accordance with two technical directives that are issued by Energinet.dk based on EU regulations. One directive concerns the disconnection of customers in order to prevent major blackouts and the other concerns the grid telegraph – in other words the communication between Energinet.dk and the DSOs.

The voltage drops

The frequency on the Jutland-Funen grid drops to 48.7 Hertz... that's not good at all! The frequency should be at 50 Hertz so a lot of customers have their supply interrupted.

"The situation appears critical. We must consider raising our preparedness", is eccoed around the room at Eniig.

Messages are now rushed out to internal and external partners – for example the press and small electricity DSOs in Eniig's area. All customers are split up into ten groups (Steps 1 to 10) across the length and breadth of the three main areas (North, East, West). Approx. 35,000 customers in Steps 1 and 2 are without electricity. If the event took place in reality, the energy company would now be deluged by customers phoning in.

"Maybe we should start to think ahead... this could get worse", somebody suggests.

Energinet.dk indicates that a 400 kV line in northern Germany is out of action. A crane has collapsed into the high-voltage masts near Audorf north of Hamburg, and the western Danish grid is no longer connected to continental Europe. The electric motorway is closed and the local roads are overloaded.

"Why can't we see the frequency on the grid telegraph?", somebody asks.

Morten Eriksen and the two exercise observers are busy taking notes... both large and small. At the end of the exercise, what has been learnt and any loose ends will be discussed with the other DSOs and Energinet.dk so the procedures can be optimised.

75,000 customers without electricity

In a crisis situation it is easy to disconnect many customers in the major cities, but it is more difficult to get the volume out to the rural areas. CHP plants and wind farms must remain on the grid in order to contribute to its stability. Hospitals and police stations typically manage by themselves – they have emergency generators.

Many situations are considered in advance – now they are super-relevant. Energinet.dk requests manual disconnection of an extra customer group and Michael Melgaard initiates interruption to Step 5. Approx. 75,000 customers (30 per cent) are without electricity, but the grid is stabilised at 50 Hertz.

Energinet.dk indicates that there may be power shortages for 12 hours. If possible, customers should not be without electricity for more than two hours, so Eniig starts to prepare a rolling brownout, where new customers are disconnected and others come back on line.

"This 30 per cent must be maintained, so we disconnect Step 3 and connect Step 1. Then disconnect Step 4 and connect Step 2", is the conclusion following a long debate.

"Danes have electricity in their power sockets 99.99 per cent of the time, so our system works. Nevertheless it is important that we always remain alert in our daily work as well as in the future. We must maintain and invest in new things - practice new routines and deal with unexpected events."

Jørgen S. Christensen, research and technology director, Danish Energy Association

Threat triggers new exercise

Just after 10.30 am, Energinet.dk issues a message that there is a terrorist threat against Denmark. A terrorist threat triggers a different type of reaction from the DSOs, so there is now an exercise within the exercise. The electricity sector's emergency plan and Eniig's own plans are leafed through carefully.

Energinet.dk requests Eniig and the other DSOs to implement a series of measures. All employees now carry visible identification and no guests are permitted to wander alone around the building. The gate to the area remains closed.

Break! At Energinet.dk the sweat is evident. The TSO surveillance ask everyone to "freeze" their activities while those responsible create a plan. At Eniig, the break is used for discussions:

"We need to have more uniform lines of command", somebody suggests.

"If we have to have rolling brownouts, maybe we should maintain our division in the North, West and East, to keep an overview of the whole situation", a second person suggests.

Back to normal

Shortly after midday, the customers in Step 3 are connected and "only" 20 per cent are without power. At 1.00 pm, Energinet.dk has taken control of the situation thanks to capacity from eastern Denmark and important foreign connections. At two o'clock the situation returns to normal and the terrorist threat evaporates.

Energinet.dk acknowledges today's good cooperation via the grid telegraph: The system works. The interventions prevented a major disruption.

Claus Holmgaard is monitoring operations during the exercise. At his side is operator Michael Meldgaard. Around Holmgaard and Melgaard, men in their prime buzz around to observe, comment and learn from today's events. Photo: Lars Horn

Hired as a

"Wind and weather can provide challenges for the electricity grid, but through digitisation we have increased our focus on IT security. The horror scenario is that many customers lose power over a longer period of time. This happened to the Ukrainian energy company Prykarpattyaoblenergo on 23 December 2015, after some very skilled hackers had attacked the system. 230,000 West Ukrainians were without electricity for up to six hours."

Peter Kjær Hansen, senior consultant, Danish Energy Association

DSO SEAS-NVE has approx. 400,000 electricity customers and therefore approx. 400,000 points of attack for hackers. Photo: Hanne Loop.

hacker

A Master's project has taken engineer Emil Gurevitch across the world. He is now on his way to Silicon Valley, after having tightened IT security at SEAS-NVE and many other DSOs.

When Emil Gurevitch agreed to attempt to break into the DSO SEAS-NVE's IT system as part of his Master's project at the Technical University of Denmark, he had never considered that he would get so far into the system… and so far out into the wider world.

"The report that I wrote is still confidential", says information security engineer Emil Gurevitch, 29, via a phone call from Gdansk in Poland, where the American company Networked Energy Services, NES, has its European head office, and where he is waiting to get a visa to the USA so he can return to Silicon Valley.

Confused? We should really begin elsewhere – namely the department manager for meters and installations at SEAS-NVE, Bo Danielsen. IT security in remotely read metering systems is close to the heart of SEAS-NVE, but are there holes that hackers could penetrate? Bo Danielsen believes that it is wise to challenge themselves and their systems from time to time.

"We are one of the first DSOs to use remotely read meters and we now have an active network with almost 400,000 points of attack", he says.

Communication via the grid

Years ago, SEAS-NVE bought the meters from Echelon, which has since become the aforementioned NES. The digital meters communicate with SEAS-NVE's IT system over the grid, and this should be a safe way to obtain the data to correctly bill customers' energy consumption. Other energy companies have experienced attacks from hackers, so SEAS-NVE turned to DTU Compute to learn more.

Their dialogue showed that there are actually not many researchers in the world who know something about IT security and remotely read metering systems in DSOs. The solution was to ask one of the information technology students, Emil Gurevitch, to test SEAS-NVE's system. At the time in the spring of 2014 he lived in a small apartment in Copenhagen and had heard a little, but not much about SEAS-NVE.

"We had some good discussions on the set-up and established some ground rules. It had to be as realistic as possible", Emil Gurevitch remembers.

Meter taken to pieces

SEAS-NVE supplied him with a meter and a login so he could attempt to hack into the system like a perfectly normal customer in the comfort of his living room. The time frame for the whole project was set at four months and the agreement was that he obviously must not misuse the data that he would have access to.

"The first thing I did was to try and understand the system better than those that had created it. The meters communicate over the grid and the technology is very different to over the internet. The task captivated me from the start. I was involved in something that I would not be able to learn at university", says Emil Gurevitch.

He took the meter apart and examined the network… and managed to penetrate further than Bo Danielsen would ever have imagined possible.

"There are different levels of security. Can you hack one meter? Can you access a different meter in the same subnet? And can you access other meters in other subnets? So we were now involved in a classic hacker scenario", says Bo Danielsen, and notes that Emil Gurevitch was awarded the highest grade for his Master's project and thus became an engineer in information technology, specialising in security.

Employed in California

Emil Gurevitch had therefore demonstrated that it was possible to access the meter, so SEAS-NVE began a series of discussions with the supplier in the USA. The management of NES were very responsive and the dialogue was followed by formal cooperation between NES, DTU Compute and SEAS-NVE.

"Confidence in the meters, communication network and IT system is critical for SEAS-NVE and the same naturally applies to our suppliers", states Bo Danielsen.

Emil Gurevitch, who until that point had been living off a student grant from the state, was recruited by SEAS-NVE and seconded to NES in California. The result was improved algorithms and software and network updates which have now been implemented in the meters and network as a whole at SEAS-NVE and other DSOs around the world with the same technology.

"They made improvements to security that they did not realise they needed", notes Bo Danielsen and stresses that access to the grid via the meters could have been damaging, but that malicious hackers could not have accessed power plants, for example, using the same method. The meters "only" deliver packets of information (hourly values every 24 hours) to Denmark's central DataHub, which is operated by the transmission and system operator Energinet.dk.

Dream job

Hackers are constantly finding new holes, so SEAS-NVE now continues to work closely with NES and other suppliers. Bo Danielsen is happy to praise the Americans for being open to "a foreign guy" and he is pleased that Emil Gurevitch has been given a job at NES.

"We now have a close and direct relationship with a very important supplier. Emil's skills are best put to use by being at the forefront of new software developments. In this way we have created a win-win situation", states Bo Danielsen.

SEAS-NVE has sent Emil Gurevitch on an agreed hacking mission to improve IT security. He is now on his way to Silicon Valley in the USA. Photo: Private photo.

Emil Gurevitch says that he was already interested in software and network security as a hobby before the project. He would have been willing to carry out the test at SEAS-NVE in his free time, so the development has been a dream for him.

"It has been and still is an enormous motivation for me to close holes in the energy industry, which is a key sector we are all dependent on", says Emil Gurevitch, who now cooperates with energy companies across large parts of Europe.

His plan is to move to San Jose in the middle of Silicon Valley:

"It is an interesting place to live for IT geeks like me. There is a very special dynamic. I have to pinch myself occasionally. My report to SEAS-NVE has opened doors to the energy industry and given me a dream job. My story shows that there is enormous value in dragging students out of the closed environment of their university", says Emil Gurevitch.

Regulation should reward – not punish – innovation

More and more power is produced locally, and this gives European DSOs an ever greater role in developing an intelligent and efficient energy system. Regulation of the DSOs must therefore encourage research, development and demonstration, says the industry organisation Eurelectric.

Over half of Danish electricity production is now fed into the distribution grids, and the volumes are increasing year on year.

The grid in Denmark – and many other places in Europe – is about to be turned upside down thanks to this decentralisation with electricity production from wind turbines and solar cells. At the same time, more and more electric vehicles and heat pumps are coming on line, which is providing whole new load profiles on the local grid.

For several years, the UK, Finland and Norway have offered their DSOs incentives for innovation to ensure good and effective grids. France, Italy and several other countries are about to follow suit, and this is both positive and necessary, believes Eurelectric, the trade association for over 3,500 energy companies in Europe.

"DSOs play a key role in the introduction of new innovative ideas that can improve the grids and develop a smart energy system for the benefit of customers. As the DSOs are natural, regulated monopolies, they develop innovative concepts within regulatory frameworks", writes Eurelectric in the report "Innovation incentives for DSOs – a must in the new energy market development".

Power grids as guinea pigs

Deputy Director General Anders Stouge of the Danish Energy Association agrees that there is a need for innovation.

"Regulation in Denmark encourages the DSOs to lower costs. This is to be expected as natural monopolies must of course be run efficiently, but there must also be economic scope for development.

"If the DSOs are only encouraged to make short-term cost reductions they will ossify, and society will pass a large bill onto the next generation. Short-term efficiency now must not be sought at the expense of optimal solutions for customers in 2025 or 2030", says Anders Stouge.

Europe's energy system is in the middle of a tremendous upheaval, and to keep pace with the change, DSOs must participate in innovation projects with their expertise in grid operation and with technical installations as "guinea pigs".

"DSOs are the only ones that are able to test new ideas – including flexible power consumption – close to the customers, which is essential to bring research results out of the laboratory and into real applications", Anders Stouge points out.

Need to think long term

EU heads of state and government have adopted a series of energy and climate goals for 2030, continuing the decentralisation of the energy system. Governments and energy supervisory bodies must therefore take inspiration from the Eurelectric report:

"We need to think long term. Denmarks ranking in the report is far from impressive, so there is room for improvement. With the electricity grid we are dealing with an investment heavy infrastructure that just has to work", says Anders Stouge.

Intelligent solutions are not just about managing electricity consumption better for the customers and to optimise grid operation. Anders Stouge points out that there may be considerable benefits to be had from thinking across the supply types – in other words, ensuring interaction, for example between electricity, district heating, gas, water/sewage, waste and transport in "smart cities".

In 2016, the Danish Government launched a new supply strategy, also seeing the potential of thinking across sectors.

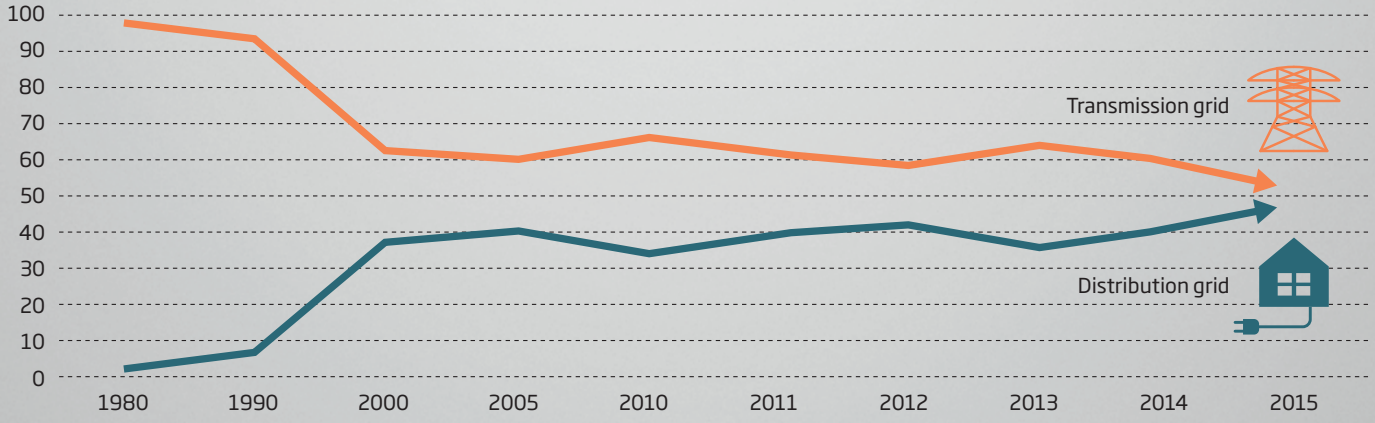
"Hopefully this will be reflected in regulation of all the sectors involved, so we can develop new technical solutions and business models", says Anders Stouge, quoting the Eurelectric report: "If we don't do something and just treat innovation like any other cost, regulation will not be neutral but actually equate to less innovation."

Anders Stouge points out that through innovation, the European energy companies can cooperate with scientists and suppliers and industry to develop smart solutions and create jobs and increase exports. The 2015 UN climate agreement from COP21 in Paris has been ratified and virtually all countries in the world have promised to aim for the lowest possible CO_2 emissions.

Read the report at **www.eurelectric.org**

Electricity production is increasingly linked directly to the distribution grid

The share of electricity production which is connected directly to the distribution grid (Source: Danish Energy Agency, Energinet.dk)



Over half of Danish electricity production is now delivered into the distribution grids from wind turbines, CHP plants and solar cells. The volumes are increasing year on year.

Think laterally and reinvent!

There are many positive benefits for society if the supply companies start to think across the electricity, transport, heating/cooling, water, sewage, waste and gas sectors. Regulation of these sectors should reward and not impede innovation, according to energy company EWII.

A small mobile coffee bar races through the streets of Copenhagen, spewing out dirty exhaust fumes, but it does not have to be like this.

Energy company EWII has developed the TRIPL electric vehicle which Peter Larsen Kaffe has adopted and now serves noise-free and smoke-free coffee in the Danish capital.

The TRIPL vehicle can also be used to deliver parcels and pizzas, and is a perfect example of innovation across the sectors.

"We can create SO many positive benefits for society, if we think across energy and transport – and across electricity, heating/cooling, water, sewage, waste and gas", says Charles Nielsen, the director responsible for infrastructure in the multi-energy company EWII, which includes TREFOR El-net.

However, the current regulation of utility companies impedes many good initiatives. Charles Nielsen is therefore calling for 1) more uniform treatment of different types of utilities, 2) a reform of energy taxes and tariffs and 3) long-term frameworks for DSOs that reward innovation.

China and India moving forward

"China and India are making amazing technological progress, particularly in the field of wind energy, solar cells and batteries. If we in Europe are to maintain and develop our industry, we must do something different and think across the sectors", says Charles Nielsen.

He points out that the energy sector is facing a revolution, likes of which has never been seen before. In the future, energy will not be something we extract from underground – energy will be something that we harvest from the wind and the sun.

As a consequence of the conversion, electricity prices will be determined by small marginal production costs. Wind turbines and solar cells do not incur any fuel costs, so on the whole they will produce electricity whenever nature permits.

"Our legislation and thinking is still very silo-like and based on fossil resources. This needs to change. If we are able to see across the sectors and optimise our total energy and supply systems, we will be in a strong position", Charles Nielsen says.

Cleaning pure rain water

EWII has its origin 150 years ago around the towns of Middelfart, Kolding, Fredericia and Vejle. There is great potential in this growing area to make use of waste heat and other energy from water treatment plants and industries. Society can also make big improvements to the supply of drinking water and sewage treatment:

"It is highly inappropriate that water treatment plants receive significant quantities of (almost pure) rain water which must be cleaned, and that we use clean drinking water for many purposes where we could use secondary water", says Charles Nielsen.

He emphasises that the EWII Group would like to see more innovation and that the various branches of the company are involved in a series of ongoing development projects. Much initiative trickles bottom-up, but if Denmark – and other European countries – seriously want to make progress, there must also be pressure from above from governments and the EU.

Charles Nielsen, director for infrastructure in multi-energy company EWII - including TREFOR EL-net.

Through efficient operation, TREFOR offers customers low network tariffs. This is also the long-term ambition, but...

"If we are to secure our long-term future, there needs to be more room for innovation. The very fact that the political rhetoric is solely focused on "cutting back and making it cheaper" hinders the development of new solutions, products and services", says Charles Nielsen.

Bornholm combines biomass, wind and solar

Island energy: Bornholm will be CO_2-neutral in 2025 – without additional onshore wind. Bornholms Energi & Forsyning is analysing alternatives in its own simulation tool and the first calculations show that there is room for more solar cells in the grid than expected.

"We must have more data and knowledge about the system. It is vitally important and fortunately we are making good progress."

Managing director Rasmus Sielemann Christensen of Bornholms Energi & Forsyning is insistent, and you feel that he would cast the message in stone if he could: It is vitally important to increase our level of knowledge, not just in business, but also in the energy system and on Bornholm as a whole.

Bornholm is situated in the Baltic Sea a good distance away from the rest of Denmark, and in terms of electricity, the island has closer links with Sweden. It happens now and again that undersea cable fails, leaving approx. 40,000 Bornholm residents stranded. Completely alone.

"It makes us vulnerable, and our grid must work. We are continuously analysing how we can increase uptime, for example through service/maintenance and new plants," says Rasmus S. Christensen.

CO_2-neutral without more wind turbines

The Bornholm Regional Municipality which owns the supply company has declared the island a "Bright Green Island" in order to attract new residents and tourists – in other words to create growth and jobs to prevent the island from entering a downward spiral.

The local politicians have set a target for the island to be CO_2-neutral by 2025. The task has been more difficult following a decision that no more turbines may be erected on land in order to protect the unique nature on the island. A majority on the local council thus removed one of the cheapest means of producing electricity – and pushed Bornholms Energi & Forsyning into unknown territory.

"We are willing to take responsibility for establishing some sustainable solutions. We have a simulation tool with data for both energy consumption and energy production. We now use this to look at how far we can go without more wind power, and we have already learnt some important things. For example, it has been shown that there is room for much more solar energy than we thought, and that solar power stations fit better in the energy system than expected," says Rasmus S. Christensen.

The simulation tool is also used for grid planning by the group's grid operator Bornholms El-Net, as well as for research and development including with PowerLab at DTU (see page 29) and in EcoGrid 2.0.

Flexible power consumption

Long-term security of supply on Bornholm and other areas with a high share of renewable energy depends among other things on whether more flexibility can be introduced on the demand-side. There is therefore a lot of attention on EcoGrid 2.0, where 1,000 Bornholm families will make their heat pumps and electric radiators available for an experiment in intelligent control. The project will show how electric heating can be optimized for the future power system where the energy mix will be biomass-based CHP as the base load for varying production from the wind and sun.

Whether or not Bornholm achieves its climate goal in 2025 remains unclear while the island's own electricity and district heating supply is part of this goal. Wind turbines cover up to 90 GWh per year and solar cells so far contribute almost 10 GWh. The important CHP plant in Rønne has just been converted from coal to sustainable biomass, so most of the electricity consumption of approx. 230 GWh will be covered with green electricity. The island's district heating is produced on the basis of typical local wood chips and straw, so this is also CO_2 neutral.

There are still several thousand oil-fired furnaces in peoples homes, just as the transport sector for the most part runs on petrol and diesel, even though electric vehicles otherwise fit in well with many Bornholm residents' driving patterns. If the CO_2 balance is to go neutral in 2025, the electricity sector must compensate with much more CO_2-free production… and this may be done with solar power plants.

"Bornholm is Denmark's sunshine island. We have more hours of sunshine than the rest of the country, but the politicians will have the final say in whether we invest in solar power plants. Technically, it fits in well with our supply system," says Rasmus S. Christensen, and it is economically attractive considering the price trend for solar cells: The latest tender in Denmark was won by solar cells, to supply electricity at the market price plus just 12.3 øre/kWh.

Traditionally, Bornholm energy companies have owned the island's production plants, but Rasmus S. Christensen is open to more cooperation with external project developers.

"For us it is more important to ensure good interaction between the plants and a high reliability of supply than to actually own the plants," he says.

Smart electric vehicles

Multi-supply company Bornholms Energi & Forsyning is the result of a recent merger between the electricity supplier Østkraft and the district heating company Bornholms Forsyning. New company – New strategy:

"We have brought our research and development activities together in one department. The idea is that on the one hand they should think across the traditional supply types, and on the other hand they should have a positive knock-on effect on our operations… but not necessarily in the short term," says Rasmus S. Christensen and mentions that the company has just participated in an international project on the smart control of electric vehicles: Vehicle-to-Grid (V2G).

Together with an international partner, Bornholms Energi & Forsyning is also well ahead with simulations of battery technology and experiments with combined solar cell and battery installations may be next on the list. According to the director, participation in this kind of research, development and demonstration will attract knowledge-based jobs as well as energy and climate tourists to the island.

"As I said: We are well into the process of bringing more knowledge into the system," says Rasmus S. Christensen.

EcoGrid 2.0 provides knowledge for DSOs

Almost 1,000 Bornholm families are making their heat pumps and electric radiators available for the R&D project EcoGrid 2.0. One of the tasks is to develop a market for the flexibility services which the grid needs in the future in order to get electricity production and consumption to match each other second by second.

To control one heat pump or one electric radiator is not so valuable for the electricity system, so the idea is to "pool" customers by means of aggregators that control many electrical devices on behalf of the families within the comfort limits they set.

Bornholms Energi & Forsyning provides the grid and assists with customer contact. The project also involves IBM, Insero Software, Uptime-IT, DTU Elektro, CBS, KRUKOW, 2+1 and project leader the Danish Energy Association, who will ensure that the results will be used by the DSOs and electricity suppliers.

Bornholms Energi & Forsyning is participating in a number of projects which will help to pave the way for a future grid with more renewable energy – and more electronic devices at customers. Photo: Anders Beier/EcoGrid 2.0

Test, test,

Fotos: Torben Nielsen

Danish-Chinese cooperation on innovation

The Technical University of Denmark (DTU) has initiated collaboration with researchers and energy companies in China to increase the share of wind energy in the grid and to make use of electricity for heating among other things. Over a period of three years, the EPIMES project will make it possible to incorporate more wind energy in the Danish and Chinese grids.

Henrik Bindner, a researcher in the Electrical Engineering department at DTU and the Danish project manager, sees great prospects in the cooperation:

"If we manage to convert 30 per cent of Chinese energy production to wind energy by 2030, it will save the planet 1.1 gigatons of CO_2 per year. This is the equivalent of 3 per cent of total global CO_2 emissions in 2014," he says, pointing out that the cooperation with China gives DTU a unique opportunity to test energy models on a very large scale.

CTO Jørgen S. Christensen from the Danish Energy Association calls the agreement "a feather in the cap" for DTU.

"China is a motor for the development of energy technology, so it is a positive thing that DTU has now embarked on a closer cooperation with Chinese researchers and practitioners," he says.

China established over 30,000 MW of new wind turbine capacity in 2015 alone. Partly because of the lack of high-voltage power lines and market rules that favour coal-fired power plants at the expense of CO_2-free electricity from wind turbines, many of the turbines are not turning even when the wind blows. The waste is huge: Up to 35 TWh/year.

For several years, Denmark and China have worked under the leadership of the CNREC renewable energy centre in Beijing to develop new solutions, and EPIMES has added a new dimension to the cooperation, including the elite Tsinghua University and several Chinese electricity suppliers. The Chinese are particularly keen to investigate and demonstrate how heat pumps and fuel cells can be controlled so that electricity can be converted efficiently to gas and heating.

test!

At PowerLabDK, 100 researchers are cooperating with students, electricity customers and businesses to develop intelligent energy technologies in laboratories and the real world.

Testing transformer stations and the charging infrastructure for electric vehicles. Testing control cables for underwater robots and new conductive materials for the operation of electric trains. Development of components for wind turbines. Analysis of what batteries can be used for in the grid.

As one of the world's leading energy laboratories, PowerLabDK contributes to the development of many of the components that will make the grids of the future work efficiently. With more and more wind turbines, solar cells, electric vehicles, batteries, heat pumps and other forms of electronics on the distribution grids, the complexity and demand for well considered solutions continue to increase.

"We help to develop new technologies and solutions, and we do this in an environment where we bring the various players together," says professor Jacob Østergaard of PowerLabDK, which is housed in a number of locations in the Center for Electric Power and Energy (CEE) at the Technical University of Denmark.

Approx. 100 researchers use PowerLabDK, which has also developed into an important environment for training the next generation of engineers. Researchers and students meet both businesses and normal families in laboratories and on real life demonstration projects such as Ecogrid 2.0, EnergyLab Nordhavn and a Vehicle-to-Grid (V2G) project at Frederiksberg.

"We have fantastic opportunities to demonstrate the energy technologies of the future, both with regard to the individual components and as system solutions with large scale tests on Bornholm," says Jacob Østergaard.

He points out that other laboratories in the world (including NREL in Boulder, USA) can do something similar to PowerLabDK, but without the ability to bring together world-class facilities from fundamental laboratories in the same way for full scale testing.

"Bornholm as a live laboratory combined with the other facilitates is what makes PowerLabDK unique," adds the professor.

PowerLabDK is currently commissioning a new data centre which will offer a greater opportunity to handle the huge amounts of data that will be an important part of future energy systems.

PowerLabDK is also equipped with the world's largest amplifier of its kind for the performance testing of electrical components such as charging points for electric vehicles, and with Europe's most powerful real-time digital simulator for development and testing. It can be used, for example, to study the interaction between power produced by wind turbines and the energy system as a whole.

Facts about PowerLabDK

The partners behind PowerLabDK are DTU and Bornholms Energi & Forsyning, the Danish Energy Association and the companies ABB, Balslev, DONG Energy, Energinet.dk, Hofor, IBM, NKT Cables, Siemens, Vattenfall and Vestas Wind Systems.

PowerLabDK consists of laboratory facilities at DTU in Lyngby, Ballerup and Risø as well as on Bornholm. These include:

- Electric vehicles with a focus on system integration
- Testing and development of rotating machines and drives
- Development and testing of future converters to energy-efficient consumption units and renewable energy solutions
- The world's largest amplifier of its kind which can be used for the performance testing of electrical components
- Europe's most powerful real-time digital simulator to study the complex interaction between individual components and the energy system as a whole
- Large scale test facility at Risø near Roskilde for the testing of data-based controls with a number of houses, wind turbines, solar cells, batteries, electric vehicles and heat pumps
- The Bornholm energy system including control room

Urbanisation requires a fine-tuned infrastructure

"EnergyLab Nordhavn – New Urban Energy Infrastructures" tests batteries, heat pumps, electric vehicles and other solutions while a new urban district grows.

Like many other cities in the world, Copenhagen is currently growing at a fast pace, which brings a number of considerations for the DSOs who are supplying future-proof infrastructure for the new urban areas.

One of the places in Copenhagen where the cement mixers are busy and the cranes are towering over the city is in Nordhavn. 40,000 new homes are being built alongside 40,000 workplaces overlooking the waves and ships on the Øresund, led by urban development company By & Havn. The ambition is to create a sustainable district.

"Nordhavn will be a place where people live close together and where it is necessary to optimise infrastructure," says Christoffer Greisen, project manager for one of Denmark's largest R&D projects in the smart grid: EnergyLab Nordhavn.

EnergyLab Nordhavn gives energy companies, equipment manufacturers and researchers the opportunity over a period of four years – with the support of state EUDP funding – to test new solutions in close dialogue with residents and businesses. This is about installing hardware, for example in the form of heat pumps and batteries, but it is also about innovative thinking in terms of concepts and markets.

Battery to eliminate peaks

Important keywords for EnergyLab Nordhavn are "system integration" across electricity, heating and transport, and "flexible consumption". In a few years, wind energy in Denmark will supply more than 50 per cent of electricity consumption, so storage and active customers will be increasingly important.

One of the elements in the grid in Nordhavn is a large battery (630 kW/460 kWh) which is owned and operated by the DSO Radius. The battery is connected on the low-voltage side to a 10/0.4 kV transformer station in a multi-storey car park.

Project manager Poul Brath from Radius explains that energy from the battery is used when there is a need to reduce the load on the grid, which can then be operated more cost effectively. The idea behind the demonstration is to learn something about design, procurement, installation and operation. Two specific applications are being tested:

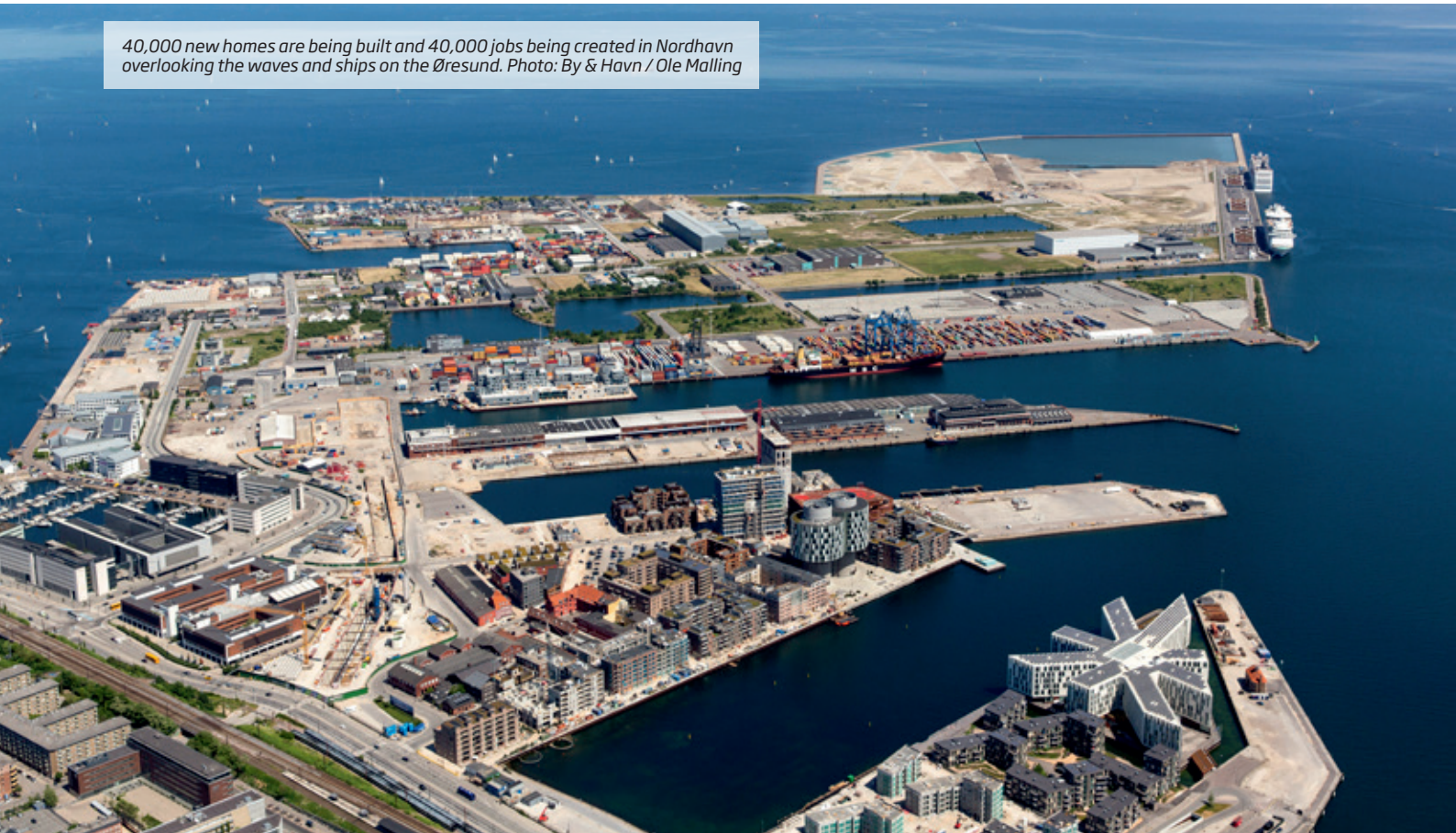
"Firstly, for a few hours each day, the battery shall eliminate the peaks from fast charging stations for electric vehicles and other large devices. We use the remaining battery capacity as primary reserves to support the main grid. In this way, the battery helps to eliminate fluctuations in the grid. We expect that this demand will grow in line with more renewable energy making it more difficult to balance production with consumption," says Poul Brath, who emphasises that Radius, which operates a natural monopoly, does not have any ambitions to purchase more batteries in order to participate in commercial markets.

However, it is important to contribute with knowledge and components while technology is maturing.

The battery is supplied by ABB, which sees batteries connected to the grid as a new strategic business area.

"The battery system is supplied as a standard item, but the control system is a new development for us," says sales manager Jonas Kehr of ABB, pointing to battery management as being at the heart of the project.

The battery system's controller is based



40,000 new homes are being built and 40,000 jobs being created in Nordhavn overlooking the waves and ships on the Øresund. Photo: By & Havn / Ole Malling

Frihavnstårnet has been rebuilt from a corn silo to residences. Until now, 13 apartments have intelligent control of lighting, electricity, heating and sensors that measure CO_2 levels and temperature. Photo: ABB.

on ABB's RTU 560 series and must ensure that the plant is controlled optimally when interacting with the grid, consumers and project requirements.

"Control is being developed so the battery can supply both peak shaving and frequency control at the same time as quickly charging an electric vehicle," says Jonas Kehr, who is looking forward to the next two years of operation that will provide ABB, Radius and DTU with a great deal of knowledge to help them develop the technology.

In addition to the battery in the parking garage, the company CleanCharge will ensure that a charging infrastructure for electric vehicles is established in Nordhavn. This will help to build a bridge between the electricity and the transport sectors.

Across the power and heating sectors

Electricity and heating will also be linked. The buildings will be supplied with low-temperature district heating and the company behind the infrastructure, HOFOR, is in the process of testing the flexibility of district heating in approx. 15 buildings in and around Nordhavn, according to department manager Charlotte Søndergren of HOFOR.

"The aim is to investigate whether smart control can reduce the need for oil-fired and gas-fired peak plants," she says and points out that Gothenburg has had good experience with reducing district heating supply for up to nine hours.

The effect on temperature in the buildings is minor, but meters have been installed just to be on the safe side.

"After the 2017-18 heating season, we expect to have learnt so much that we can determine which building types could be included in a larger roll-out of the concept," says Charlotte Søndergren.

Nordhavn is host to many cruise ships. The terminals are typically heated with oil boilers, but HOFOR is pursuing an electric alternative here. The plan is to establish a heat pump combined with an immersion boiler.

"The heat pump can be used to test how electricity and district heating can interact to increase overall system flexibility," says Charlotte Søndergren.

From passive to active consumers

An important point for all participants in EnergyLab Nordhavn is that nobody should suffer inconvience. On the contrary, the participants should have automated control of the indoor climate and optimised energy consumption as benefits in their everyday life. So far, 13 apartments in Frihavns Tårnet, the Freeport Tower, which the developer Boll+ has converted from a grain silo into housing, have been equipped with intelligent control of lighting, electricity, heating and sensors that measure the CO_2 level and temperature.

The residents contribute with data on their energy consumption, so their own, the building's and the area's energy systems are controlled intelligently.

"It is an exciting project that offers my organisation new knowledge about the opportunities available in the field of smart management of housing, while at the same time a number of residents get modern technology in their new home," says managing director Morten Boll of Boll+.

Demonstrations will show how the apartments and residents can adapt their energy consumption to varying energy production and at the same time increase comfort. Participants are thus changing their status from passive consumers to active contributors to the energy system.

The EnergyLab Nordhavn project ends in 2019, but the expansion of Nordhavn will continue over the coming decades – certainly with a better energy infrastructure than it otherwise would have had.

"We expect the solutions we are demonstrating in Nordhavn to become the energy system of the future. We already have an extremely well-functioning energy infrastructure in Denmark, but by integrating the various forms of energy we are able to increase flexibility in the energy system and thus be in an even stronger position to manage future green energy production," says Christoffer Greisen.

About EnergyLab Nordhavn

"EnergyLab Nordhavn – New Urban Energy Infrastructures" is a four-year project that uses Nordhavn as a living city laboratory and demonstrates how we can synthesise electricity, heating, energy-efficient solutions and electric modes of transport in an intelligent, flexible and optimised energy system. The project is led by the Center for Electric Power and Energy at DTU. The other partners are the Municipality of Copenhagen, By & Havn, HOFOR, Radius, ABB, Balslev, Danfoss, CleanCharge, Metrotherm, Glen Dimplex and DTU's PowerLabDK facilities.

Learn more about Danish solutions in intelligent energy and contact Danish experts at:

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