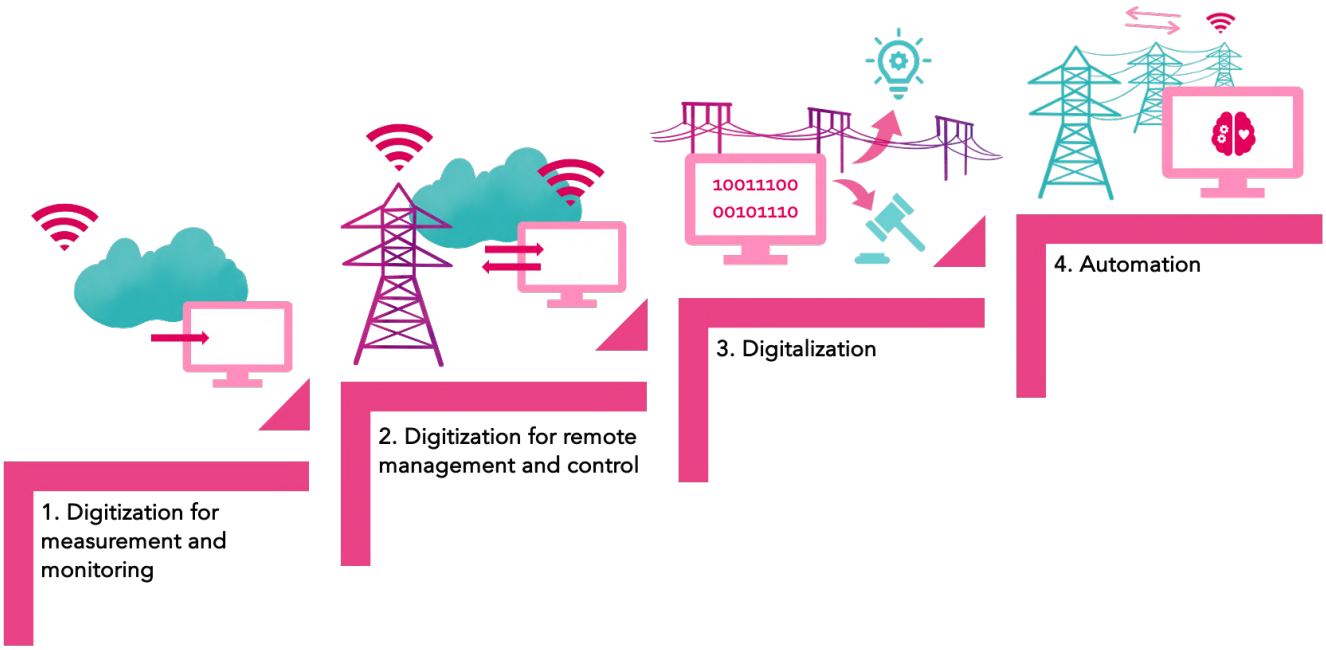
POWER CIRCLE
*Electricity for sustainable energy*

# Digitalization of the grid

WHITE PAPER FROM POWER CIRCLE

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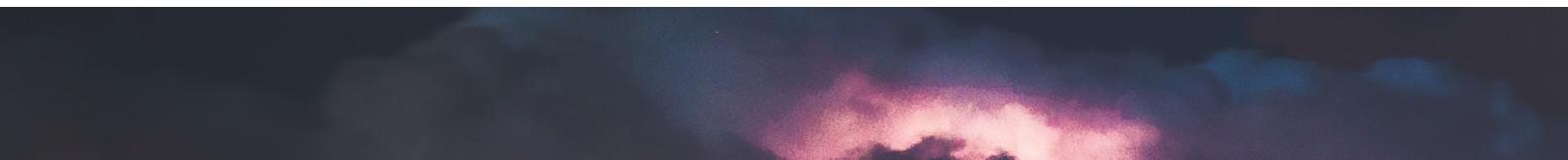


# Digitalization in progress!

**The new functional requirements for electricity meters can be considered as the first regulatory framework adopted for the grid digitalization.**

In June 2018, the Swedish government made changes to the Electricity Act and introduced new functional requirements for electricity meters.[1] The requirements aim to facilitate network operation and improve market development by utilizing extended technology for collection of raw data. By January 1st 2025, the new meters are supposed to be installed by the grid companies.

The new functional requirements for electricity meters can be considered as the first regulatory framework adopted for the grid digitalization. Simultaneously, digitalization measures are taken on several other areas to achieve different benefits and needs. While some Swedish network owners have reached different levels of digitalization, many actors are uncertain on what the term "digitalized power grids" actually entails – as well as which digital solutions should be prioritized. Whereas some actors talk about *digitalization*, others rather focus on *digitization*. The scale of the measures vary as well; pilot projects are often easier to adopt in comparison to full-scale implementation projects.

In this white paper, we want to put some light on the grid digitalization. To explain what does the grid digitalization mean, how it can be done in practice, what benefits are there and how digitalized are our grids today? This white paper is based on a project funded by Energiforsk, conducted by Power Circle in 2022.[2]

**Digitization:** The shift from the use of analog to digital technology, a tool to improve existing processes.
**Digitalization:** The transformation of digitization that improves efficiency and management over business processes, decisions and behaviours.

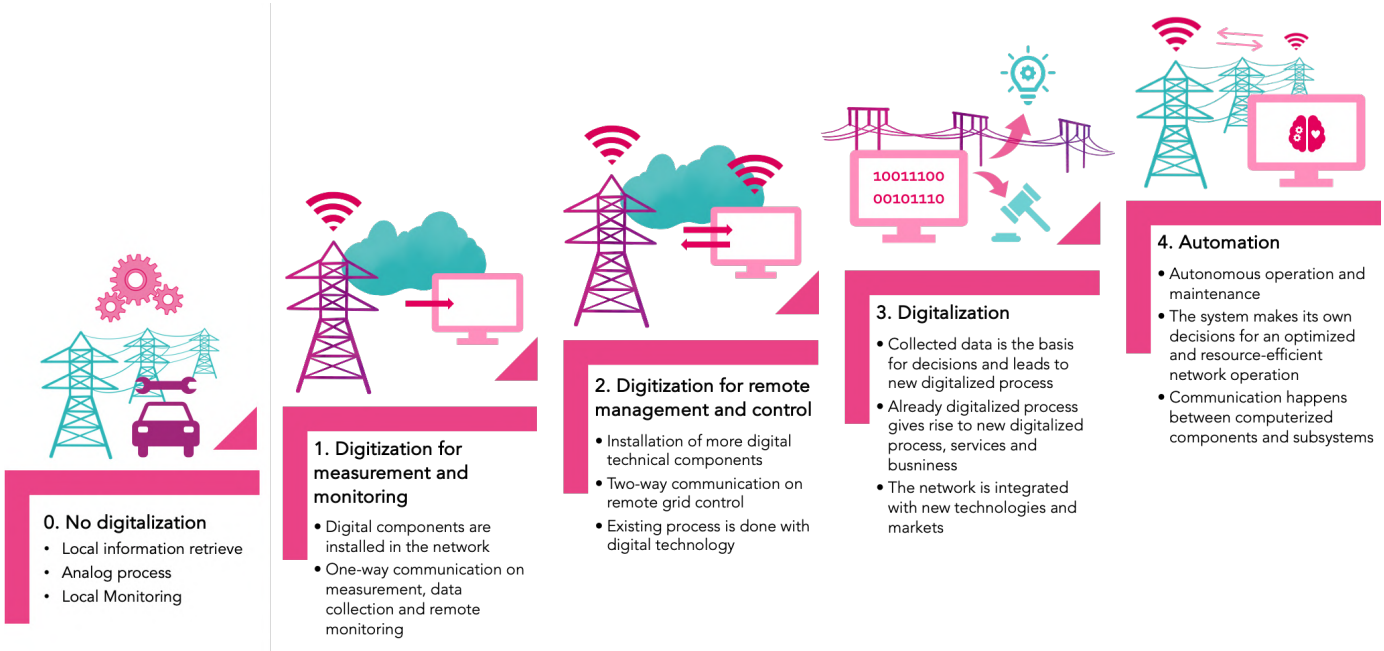
[1] Energimarknadsinspektionen (2020), Funktionskrav elmätare.

[2] Power Circle (2022), DigiGrid – Digitaliserade och resurseffektiva nät.

# Different digitalization levels

**Introducing four different levels of digitalization helps the discussion.**

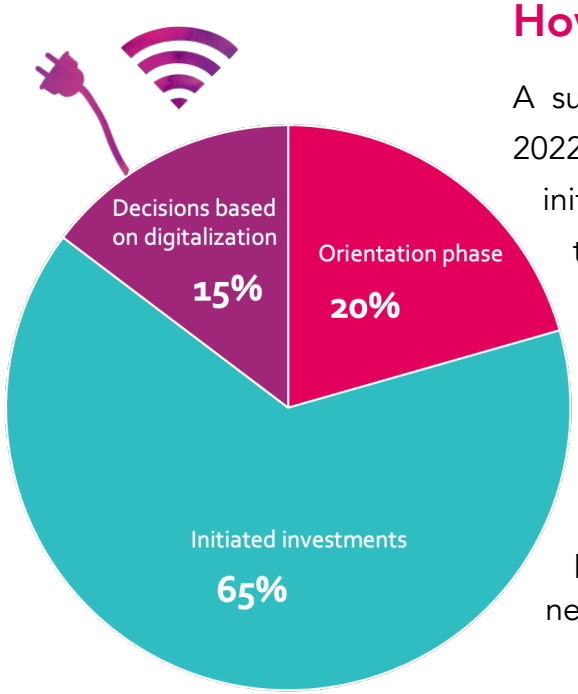
When different companies and players in the electricity system are discussing the grid digitalization, different definitions of digitalization often emerge. To facilitate the discussion going forward, we would like to introduce four levels of grid digitalization – here illustrated as a ladder, where each step corresponds to an increase of digitalization measures.




**Digitalization begins when data forms the basis of decisions, and provides opportunities for new processes, services and business.**

The first step starts at no digitalization, followed by the first step which implies one-way communication to monitor and share metrics. The second step implies two-way communication that enables remote control. Both of these steps focus on digitization, where digital technology is installed to replace analog technology.

The third step entails digitalization, where collection of data provides the basis for decisions and leads to new processes, services and business. Finally, on the fourth step, grid operation occurs autonomously – and different systems communicate with each other, making their own decisions to optimize the use of the grid.




*Current status in digitalization for electricity network companies*

## How digitalized are the grids today?

A survey[3] conducted within the DigiGrid[2] project in 2022 showed that all participating grid companies had initiated some degree of digitalization. 65 percent of the respondents had at least initiated investments, 20 percent is in an orientation phase and 15 percent stated that digitalization measures were now the basis for business decision-making. Given the previous reasoning about digitization versus digitalization, one could consider these 15 percent as digitalized businesses – while the other network owners are on their way to digitization.

The digitalization measures conducted by the grid owners largely consist of data collection and analysis, and data is collected for alarm signals, active power, reactive power, phase current, main voltage, phase voltage and energy consumption. The most common collection method is fiber communication, followed by mobile and radio communication.

**85% of grid owners collect data that are never used due to lack of time and skills.**

While some collected data are used for analysis, or help the decision-making within the businesses, 85 percent of the companies state that some data are only collected, never used, since the companies either lack of time and skills – or access to good systems that support visualization and analysis of the data. The survey also shows that digitalization measures are more advanced within medium-voltage grids compared to low-voltage grids.

[3] The responding electricity grid companies together represent around 40% of Sweden's total electricity use according to Ei:s öppna data från 2020.

**Grid owners understanding of their grids today:**

**97%** of the grid companies have good or very good knowledge of where they have solar cells connected.

**77%** have good or very good knowledge of where bottlenecks can occur in the current grid.

**74%** have good or very good knowledge of where the network needs to be expanded in order to connect new charging stations.

**65%** have good or very good knowledge of where new generation can be connected.

**30%** have good or very good knowledge of where they have energy storage connected.

**The grid owners' highest interests in digitalization:**

**88%** has interest in monitoring and analyzing online status in real time.

**79%** has interest in trend analyzes and forecasting of future power needs.

**77%** has interest in identifying bottlenecks.

**77%** has interest in inspection and troubleshooting.

**71%** has interest in the developing and controlling a distributed energy system.

## Different key drivers for digitalization

There are several key drivers behind the grid companies' digitalization efforts. By investing time and money in digital technology and new processes, most companies want to generate:

- Better knowledge and understanding of the grid
- Better network control, monitoring and management
- Reduced downtime
- Better decision-making basis and processes
- Better utilization of the existing power lines
- Improved customer experience
- Improved delivery quality
- Increased profitability.

Measures that can minimize the downtime, give ease to customers and facilitate operation and maintenance work are given the highest priorities by most grid owners - while better knowledge of the grids, operational optimization, long-term network planning and preventive maintenance are also important motives.

In the short term, companies are interested in digitalizing for the benefit of being able to monitor and analyze the status of the grids in real time, and most significantly, to increase reliability and availability. In the longer term, the companies want to have access to better decision-making information and tools for the grid planning. Increased profitability is also mentioned as a long-term goal.

# A future digitalized grid

The electricity grid in a medium-sized Swedish municipality is monitored from a control room. The screens in the control room show power flows in the grid in real time, together with data of temperatures in transformers, voltage levels and power outlets at various measurement points. Data is collected via both the customers' electricity meters and the meters installed in substations.

An alarm sets off, indicating a transformer has been overheated and tripped. The event is automatically isolated and the stations nearby begin to deliver more power to ensure that customers do not experience a power cut. This is the fifth time in seven months that a problem has occurred in the same transformer, the information about the error is logged with high priority in the grid company's system for maintenance. It is time to investigate whether any component needs to be replaced preventively.

When the sun rises the voltage changes in certain parts of the grid, several components in the grid automatically switch on to regulate the voltage. When the sun is at its highest, several flexibility bids are activated and it leads to an increase in electricity consumption in the area, so that no parts are overheated. Information about the activated flex bids is stored in the electricity network company's digital twin, whose data base continuously improves to provide the best possible support for the grid planning team. With flexibility, some grid reinforcements can be postponed further.

At the same time, the grid is being expanded at the maximum speed to meet the requirements of electrification. New customers can be connected quickly through automated procedures and are supported by a map that points out available capacity so that the customer can chose a suitable spot for charging infrastructure or new electricity production. Large amounts of previously unused historical data are now useful in AI tools, as it helps to forecast future power needs and optimize the grid performance.

# Benefits of digitalization

**The new digital technology makes grids more intelligent, and contributes to optimization and efficiency.**

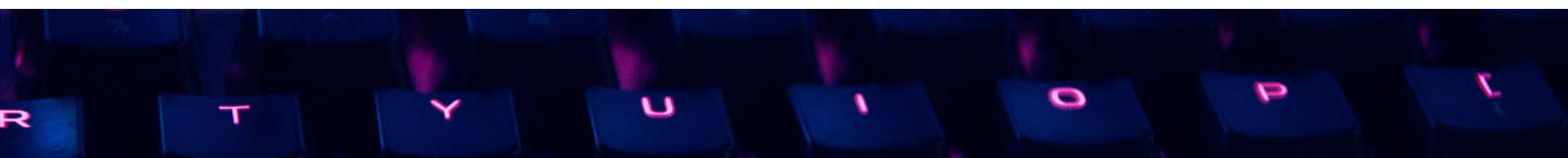
Devices, machines and facilities become more intelligent through digitalization - the same logic applies to the grids. New digital technology – with connected devices, AI, machine learning and self-planning systems – provides opportunities for optimization and increased efficiency. When grids are becoming digitalized, several direct benefits are accessed:

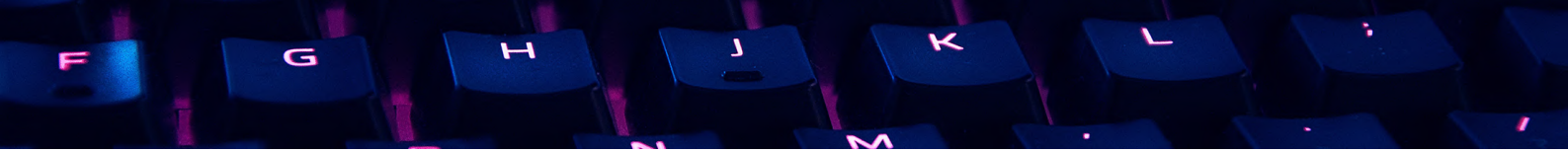
- Measurement and monitoring in real time
- Remote control and control of the grids
- Increased utilization in grid capacity
- Energy efficiency through reduced losses
- Automation, self-control and self-planning
- Long-term network planning.

**A more efficient use of the existing electricity grids can reduce costs and lead times for new connections.**

Digitalized grids enable large-scale electrification and promote energy conversion because digital processes and technologies create new opportunities for operations and maintenance. It also brings benefits and services for the new customers.

As the digital technology becomes increasingly cheaper, a more efficient use of existing grids is now possible - this can reduce investments and lead times for connecting new customers. In addition to resource efficiency, digitalized grids can also contribute to supply security when the electricity system has smaller margins and increased complexity. Examples described below show how grid companies have achieved benefits with the help of digitalization measures, and how these contribute to the network operations.





## Digital twins in the electrical system

The increasing need for knowledge and insight of the actual situation in grids is a challenge for many local power companies. For this purpose, digital twins can come in handy.

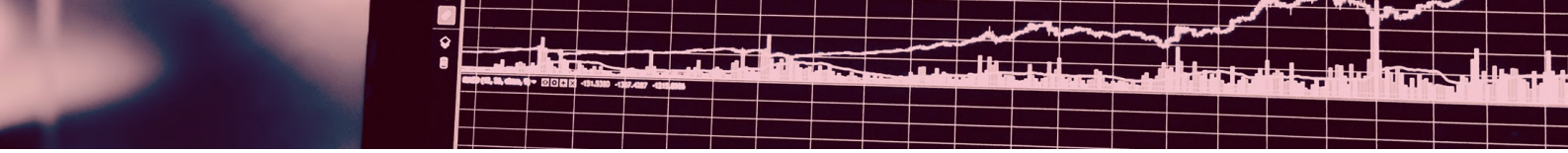
**In the electrical system, digital twins can create understanding for several different operating situations.**

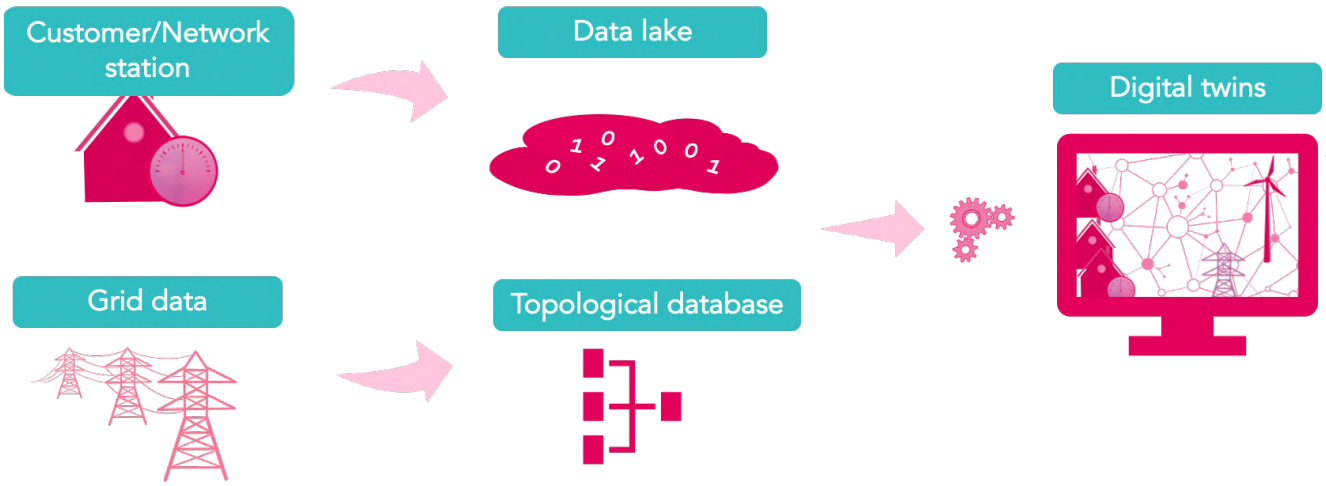
A digital twin of the electrical system consists of three parts: the physical electrical system, a digital representation of the physical system, and continuous two-way transmission of data between the two systems. Digital twins can be used for several purposes. Together with the supplier Plexigrid, the local grid owner Öresundskraft has implemented a digital twin in order to:

- Create an understanding of the current operating situation in the grid, and how it has been historically. Where are the bottlenecks? Where limits have been exceeded? And where voltage dips have occurred?
- Simulate new connections, imitate what happens in the grid if new customers are connected or if current customers need to be redirected.
- Investigate future capacity needs in the long-term grid planning.

**Different data about the physical electrical system is needed to create the digital twin.**

To create a digital twin of a local grid, the parameters that describe the physical system – such as information about power lines, nodes, network infrastructure, connected devices and all control systems – need to be compiled in a data lake and in a topological database. There are both static parameters, such as physical limitations for components in the network, and parameters that vary frequently, such as active and reactive power.






**The electricity grid consists of a lot of data, one challenge is to identify which should be collected.**

The data is collected from the meters and sensors in the physical grid, and processed to sort out incorrected values. Then the data is imported into the mathematical models that describe the dynamic behaviour in the grid. Depending on the area of use, the mathematical models need to perform calculations either in real time, near real time or at a later stage. Based on the results, automatic or semi-automatic decisions can be made - and when the decisions are made, the information can be transferred to the physical system to, e.g., make redirections in the grid.

**With the right input, the digital twin can make estimates for the entire power grid.**

It is also important to identify which data should be collected. There is a lot of data in the electricity grid and it is not possible to collect everything. However, if the right inputs are used, the digital twin can make estimates based on the entire power grid. The measurements of active and reactive power, voltage and current – that are collected via smart meters and grid stations, they are often the minimum requirement for the digital twin to function.

## Management of the flexible resources

**With digital technology, the potential of the electricity system's many flexible resources can be realized.**

More and more grid owners are interested in solving power and capacity problems with flexibility. When the electricity prices vary throughout the day, and new grid connections become more difficult to obtain, the attraction of contributing flexibility from the customers' side is getting more attention in various marketplaces.

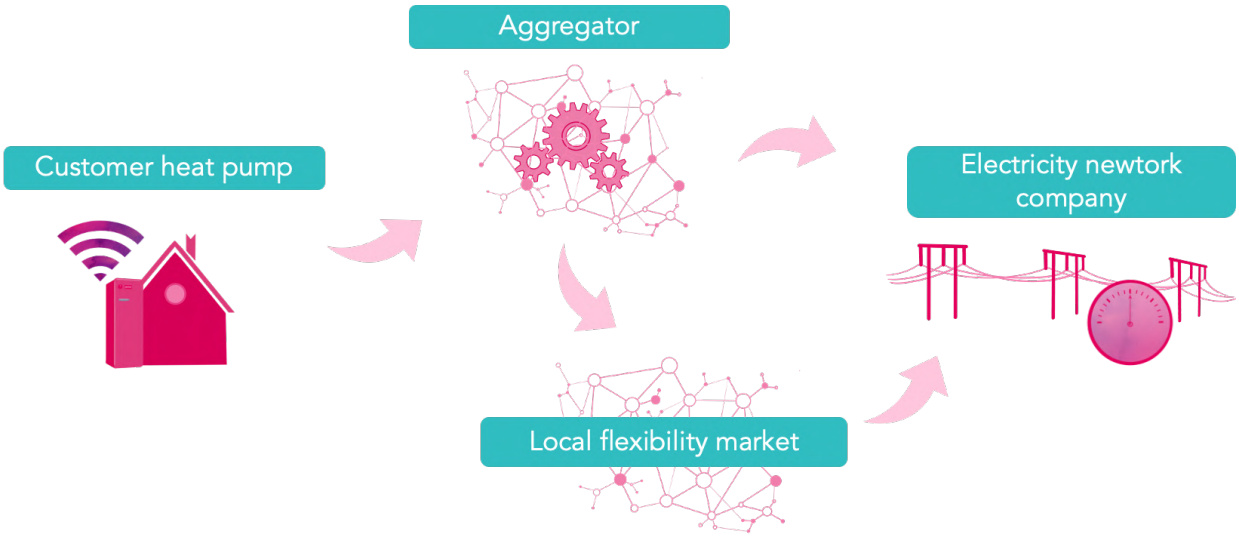
The grid customers sit on many different flexible resources, and the potential of these flexible resources can be realized to a greater degree with the help of digitalization. In the future, there is also a potential to use demand side flexibility as a grid planning tool.

**Flexible resources:** electricity users, production units and components that can temporarily reduce or increase their power consumption according to the demand situation in the network.

In Upplands Energi's local grid, the energy technology company Ngenic has installed heat pumps with smart control for approximately 500 households. Those heat pumps are able to provide flexibility services when the grid capacity is in danger of becoming overloaded. For household customers, the smart control brings more comfort and certain energy efficiency.

**Heat pumps in households need to be connected to the internet and controlled with software to generate flexibility.**

The heat pumps need to be connected to the internet to provide flexibility, the connection allows data sharing and grants pumps to receive control signals from the flexibility aggregators or the household itself. The central control system lies on the aggregator's software, whose algorithms calculate and optimize the energy use of each heat pump. The decision on energy use is based on the data gathered from temperature, solar radiation, humidity, electricity price and the need for power flexibility.




The aggregator controls the heat pump through its own app, or via an API to the heat pump's enclosed app. Currently, there is no standardized communication protocol for heat pumps. Electric car chargers, solar cells and energy storage are other examples of resources that can be controlled by their owners or aggregators to contribute flexibility.

## Digitalization of electrical substations

To reduce outage time is one of the top priorities for all grid companies. However, many grid owners today have a reactive way of dealing with outages that occur, and services engineers are only sent out to the sites after the customers have experienced an outage.

**Replacing analog grid stations tools with digital ones, errors can be detected earlier and reduce outages.**

By digitalizing grid stations, errors can be detected before the customers have to report them. Electricity can be switched on by remote control, and outage times can be reduced. At a later stage, operating data in combination with the right analysis methods can warn the personnel involved in troubleshooting and repair – even before the problems arise.

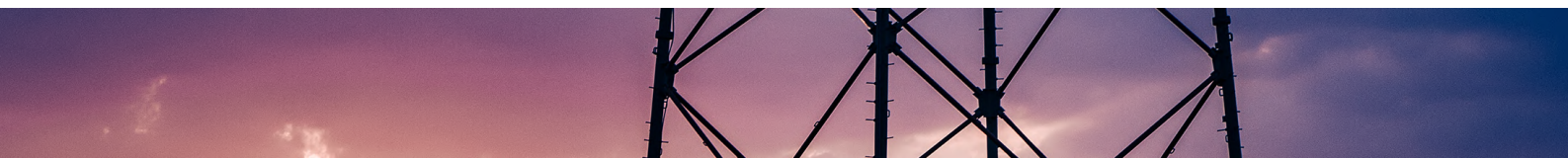
**Today, customers often are the ones who report outage. With new analyses, errors can be detected before interruptions occur.**

The grid owner Ellevio has started a digitalization program with the goal of upgrading over two thousand network stations by the end of 2030. The work began with digital documentation on the grid stations, followed by identifying which stations should be upgraded. The upgraded stations have been categorized into three levels:

- At the first level, data on voltage and current are sent in a one-way flow manner, so that interruptions and errors can be detected remotely.
- On the second level, two-way communication with disconnectors and automatic switching enables operation to remote control of the grid, so that the customers who are not directly affected by outages can get their power back.
- On the third level, network stations are equipped with relay protection and software that can authorize the stations to make own decisions. However, this demands several nearby stations to have the same characteristics as it needs an information exchange.

**Digitalization of grid stations can also lead to a better understanding of grid situations.**

The project can, on top of reducing outage times, lead to a better understanding of various network situations. The collected measurement data would be able to provide insights on predictive maintenance. Nevertheless, to take advantage of all the available data remains a challenge, as both new systems and skills are needed to manage the process. The new extended communication with the grid stations can also entail possible new security risks, which has to be taken into account in the future planning of the grid.



# Development is needed

**The right skills are necessary, but to attract the right personnel is a challenge for grid companies.**

A fundamental prerequisite for the grid companies to succeed with their digitalization measures is a good understanding of the challenge ahead. Among everything else, having access to resourceful personnel with mixed skills in IT, data communication and electric power technology is crucial to a successful digitalization. Together with that, access to installers with the knowledge of new meters and communication equipment is key. Today, the grid companies are facing a challenge to attract these skills and competences.

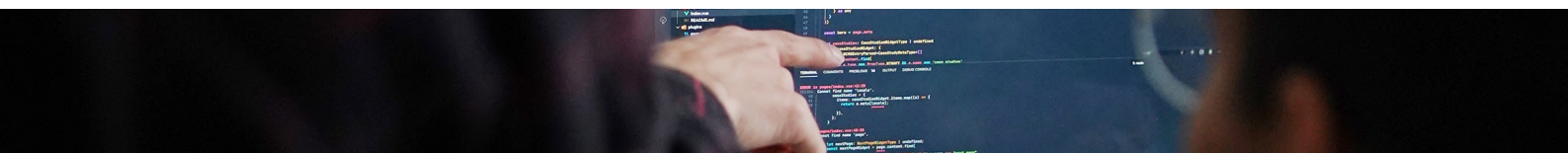
**NIS-directive:** "The directive on security of Network and Information Systems", an EU directive that sets requirements for information security in public networks and IT systems throughout the Union. It covers key services for society, such as digital infrastructure and energy, in the Swedish implementation.

To manage the collected data to a greater extent and in a better way, the companies need to have good system support for data visualization and analysis. In addition to the improved access to competence and system support, companies are also required to open up for a change in working methods, if level three and four on the digitalization ladder are to be achieved.

**Transparency, openness and shared access are important development factors to cyber security.**

In order to create the grid digitalization, several propulsive – and protective – regulatory frameworks and standards need to be developed. On top of the new Swedish functional requirements for electricity meters, the EU NIS directive[4] is to be implemented in Swedish regulation. Transparency and data openness are both challenges and important factors to push the future development as well. Hence the role of cyber security becomes more critical than ever. Nevertheless, in future, more standards are needed to facilitate the development and cooperation between electricity grid companies and various technology and service providers - both nationally and globally.

[4] Official Journal of the European Union (2016), Europaparlamentets och rådets direktiv (EU) 2016/1148.



# Summary

Grid digitalization can bring many different benefits to the grid owners, the customers and society at large. In a time where the energy demand increases and fossil fuels are phased out, it is particularly important that our existing electricity grids are used as efficiently as possible. Therefore, a continuation of digitalization is urgent, as it gives the grid owners access to new knowledge and tools to work with.

At the same time, major changes in working methods and system support are required to reach the full potential of digitalization. There is an urgent need for personnel with new skills that the grid companies currently do not possess. Meanwhile, the continuous development on information security and legalized standards are prerequisites for all involved systems to function together in a reliable manner.

Full scale grid digitalization can not be achieved by a few or individual grid owners alone. New standards, regulations and marketplaces need to be designed together in tandem with policies and industries. At the same time, the grid owners need to take the responsibility for their part in the digitalization, and they need to establish collaborations with external companies who have the skills that the grid owners lack – the skills that digitalization requires.