The value of the digital transformation

Opportunities for Distribution System Operators (DSOs)

Brussels, July 2022

Executive summary

This decade is a turning point with the energy transition acceleration. Electric grids across Europe are built, modernised, and reshaped on a scale never seen before to meet a new electricity paradigm.

Digitalisation will play a key role to transform ways grids are managed and operated. Indeed, the new grid mandate implies a distributed architecture to match the new energy paradigm, digital technologies to create business values and a cybersecurity imperative.

Five key drivers of grid modernisation are identified to overcome the challenges DSOs face and achieve the digital transformation. These are namely: ***1. reliability/resiliency, 2. efficiency, 3. sustainability, 4. operational effectiveness and 5. customer engagement.*** These challenges will be met while performing their regular tasks such as planning, building, operating, maintaining, and decommissioning their assets and serving the customers. This will lead to satisfaction of the so-called “3Ds” of digital transformation: ***decarbonisation, decentralisation, and digitalisation.***

In a short overview the core operational and organisational activities of DSOs are outlined to better understand the starting point for many DSOs on their journey of digital transformation. The importance of strategic asset management with several processes (*planning*, *engineering*, *constructing*, *monitoring*, *maintaining*, *and decommissioning of assets*) is shown and what opportunities lie in digitalisation. This leads ultimately to the fulfilment of market and customer business processes and shows how important the role of DSOs as market facilitators is and will be regardless of their state of digitalisation. With a well-picked summary of possible and utmost important technologies, the position paper shapes around artificial intelligence, digital twin technology and their proven examples. It describes the key definitions on both technologies and what to expect from them and what other developments they relate to such as machine learning, deep learning, virtual reality, augmented reality, and artificial neural networks. The importance of data collection and processing is critical to reach maturity within the fields of new technologies in the digital transformation.

If managed and correctly built the available data, new technologies and opportunities of the digital transformation will lead the DSOs to very central enablers of the energy future and thus need the best support possible in their transformation phases.

Introduction

Digital transformation is happening. The spread of advanced technologies such as remote sensors, data analytics and automation has opened a frontier for new innovative services and approaches on doing business. Distribution system operators (DSOs) have an opportunity to evaluate how they *plan*, *build*, *operate and maintain* their assets and *how they serve their customers*. For instance, automating repetitive tasks, routine designs, inspection, and maintenance activities, using super-computing to predict when and where the next outage is likely to occur and when it will be restored, would not only decrease costs but improve service quality, reliability, and customer loyalty.

For DSOs, digitalisation is mission-critical for the energy transition. Digital transformation, combined with electrification, is aiding the transition of the entire energy sector, from power plant management to new consumer services and smart grids. Customers want accessible, problem free, reliable, safe and low-emissions electricity at an affordable price with quick access to their account information – such as billing history, usage, easy-to-understand rate structure and options to save money. They also want the possibility and choice to be able to produce, use and sell their own electricity, adapt new technologies such as electric vehicles (EVs) and get notifications about outages.

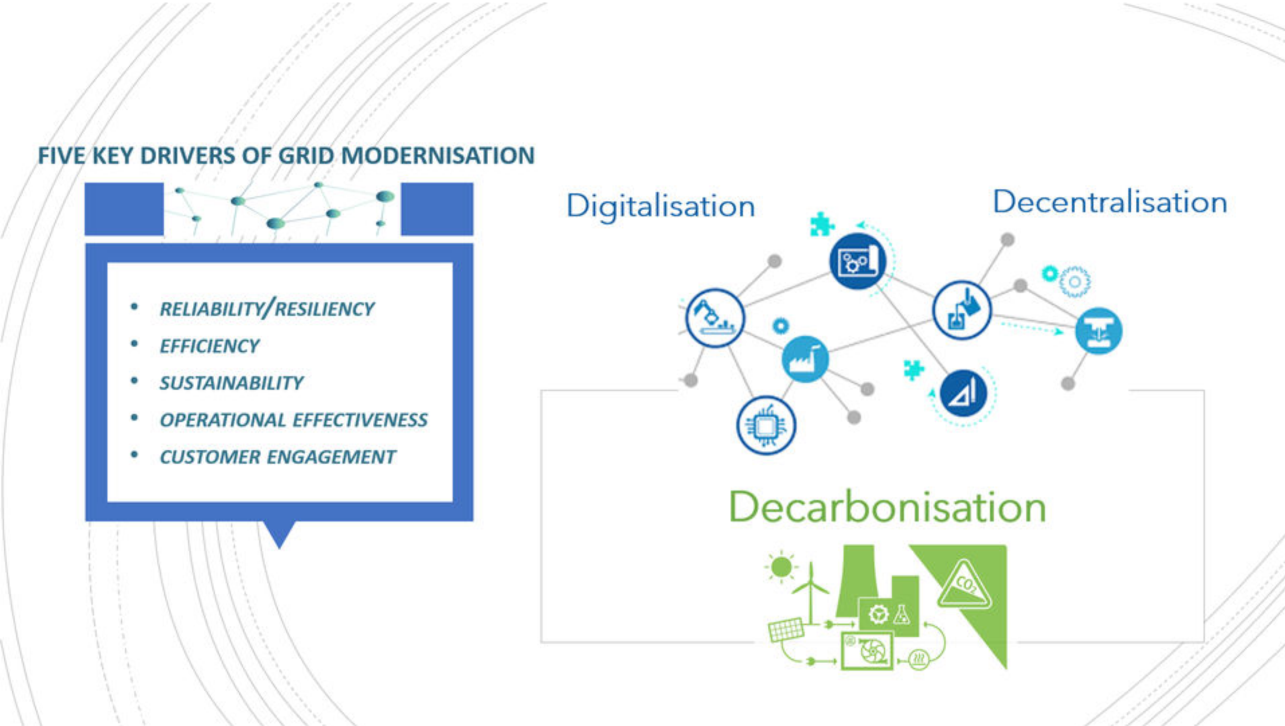
DSOs can perform the above services since they have a thorough source of information from the customer meter data that needs to be gathered to better learn the individual customer behavior and needs, and additional value-added services of interest to them.

This accelerating pace of innovation is led by key technology advancements and is laying the foundation for the digital transformation. The change is driven by some significant and inexorable trends that have redefined the distribution grid. Similarly, there are several challenges and changes faced by DSOs that need to be overcome.

There are **five key drivers of grid modernisation** that push the DSOs to overcome the challenges and achieve this transformation, namely: (1) *reliability/resiliency*, (2) *efficiency*, (3) *sustainability*, (4) *operational effectiveness and* (5) *customer engagement.*

To achieve digital maturity, DSOs must satisfy three stages of progression **–decarbonisation, decentralisation, and digitalisation** (*so-called '3Ds' of digital transformation*). The 3Ds are accompanying the new era of the electricity system by converging to produce game-changing disruptions and fundamentally reshaping the electricity system.

Figure 1: Key drivers of grid modernisation



Decarbonisation: The drive towards decarbonisation could entail significant challenges for distribution grids due to the anticipated uptake of distributed, variable Renewable Energy Sources (V-RES) and electric vehicles (EVs) connected to the grid. It is the most prevalent trend in the industry, given the urgency to act on climate change and the meteoric rise of clean energy investments.

Decentralisation: Modern DSOs are increasingly adopting decentralised models that allow power to flow on to the grid from many points or nodes, mainly from V-RES sources such as wind and solar, battery energy storage systems (BESSs) and microgrids. These models require the grid to be capable of accommodating multi-directional, unpredictable electricity flows, which adds to the complexity of grid management.

Digitalisation: Thanks to the development of favorable technological advancements, DSOs can now transform their business processes by an end-to-end sharing of information improving operations and effectiveness of customer delivery. This is propelling tremendous improvements in communications technology to optimize DSOs activities, using advanced technologies such as Artificial intelligence (AI), digital twins etc.

In a quest to remain competitive in a rapidly changing environment, DSOs are increasingly adopting digital technologies like machine learning (ML), Artificial intelligence (AI), virtual or augmented reality (VR/AR), Digital Twin and blockchain.

The new digital technologies allow data from sensors distributed in the grid at any necessary point, smart metering systems and other connected devices to be collected and delivered to the control room via wired and wireless broadband communication networks. The data can then be processed by software applications powered by AI that provide operators with detailed views of their grid and enables fast, accurate decision-making. Once integrated, these technologies can provide a host of new insights that can help DSOs sharpen their competitive edge.

The general trend toward grid modernisation is driven largely by new digital capabilities and the promise of automation that will enhance grid control and stability and improve decision-making, safety, security, sustainability and reliability.

However, key technical challenges and regulatory headwinds brought on by the growing threat of climate change represent significant barriers to successful transformation. This paper describes the layered approach to achieving digital transformation allowing DSOs to improve operations and achieve significant advantages.

By adopting the strategy 'from the field to the boardroom', DSOs accelerate the integration of cutting-edge technologies by successfully addressing the challenges along their digital transformation journey.

1. DSOs' operational and organisational activities

DSOs run several processes along their value chain. This value chain can be seen from the planning of the grids to the management, service, and operation of the physical assets, which allow for the supply of electricity to the customers, while assuring the underlying needed market processes.

The business process groups that are at the core of DSOs operation, and that allow the operation of the electric system, and consequent supply of electric energy to the consumer, are the following:

- Strategic Asset Management
- System Planning
- System Operation
- Market and Customer Business Processes

These processes are complementary between, in the perspective that one process depends directly on the information and actions of the others.

In addition to the core business processes there are support, management, and innovation processes to serve the core of the DSOs activities. These are not mentioned specifically.

1.1. Strategic Asset Management

As DSOs' infrastructure ages and impacts grid reliability, the interest in methods and tools to manage asset life continues to rise. DSOs are increasingly looking to implement intelligent asset management such as online condition monitoring, predictive asset maintenance and data analytics to gain wisdom about their asset's health. A tremendous amount of data is needed to track large quantities of equipment and assets as they are procured, installed, and maintained through their lifespan until their eventual failure or retirement.

Strategic Asset Management is the combination of management, economic, engineering, and other practices to provide the best value level of service for the costs involved. DSOs manage great amount and variety of assets, different digital technologies, and strategies, all with benefits, but which can also lead to drawbacks if not properly used.

Strategic Asset Management comprises several processes regarding physical assets:

- Planning
- Engineering
- Construction
- Monitoring
- Maintenance
- Decommissioning

With technologies such as *artificial intelligence* (AI), *data analytics*, *remote sensors*, *automation and drones*, there exists a real opportunity for DSOs to embrace technology and automate repetitive tasks such as inspection and maintenance activities, as well as outage prediction and restoration:

- The use of **Unmanned Aerial Vehicles** (UAVs) or drones is showing promising early success in aerial line and substation inspections for visual condition assessment using thermal and infrared scans, vegetation management and physical condition inspections. These inspections can scan for broken insulators, missing bolts, or a rusted member on a tower.
- There are some early developments in using drones and artificial intelligence (AI) to record field activity progress and inventory control in order to track goods as they are received and checked out.
- **3-D scans** of existing facilities make it possible to produce a 3D model and a site layout drawing, making verification of site conditions and constructability review easier without the need for multiple site visits.
- **Using Virtual Reality** (VR) to train new technicians, or to help workers during construction see the completed system, is another area of fast development. It can help accelerate equipment assembly and reduce chances of error.

- Disturbances on the powerlines due to vegetation or bird contact can be detected in the voltage waveform using data analytics tools. This detection can help DSOs' engineers scan for creeping issues before they occur and result in outage or equipment failure.
- DSOs read **smart meter data** and detect issues with home appliances. Each appliance has a certain "load-signature" that allows the DSOs to harvest the data, whether it is energy efficient or not, to keep track of issues.

The approach to asset management and asset health continues to evolve. The ability to gather, store and use analytics to make sense of large amounts of real-time data is giving rise to strategic asset management solutions that are more intelligent than the ones previously available.

Today, DSOs' asset managers can have access to fresh, higher quality data. Two main concepts should be considered to construct a solid asset management strategy with the help of digital tools, which can provide advanced data collection and computing:

- **Criticality** indicates the consequence of asset failure and can be used to determine which maintenance strategy should be followed by measuring economically the consequences of the failure. This could be done with methodologies

- The **Health index** of an asset points its condition, and correlates with the probability of failure. This should be used to determine the frequency of maintenance or the replacement of the assets.

Data analytic modelling can use both factors to make a risk-based decision, maximising asset risk reduction and business results subject to certain constraints, like limited expenditure, regulatory obligations, and business plan.

DSOs are already introducing tools using AI solutions (also based on ML algorithms) to better improve asset maintenance and services, by gathering data from a multiplicity of sources and combine them to calculate the health index of the critical assets. These technological processes allow for the most cost-effective maintenance and acquisition of assets, by extending the lifetime of the grid components to the maximum point before failure.

Last but not least the basic requirements for the electricity grid are regulated through engineering standards to provide and maintain power quality at all times for every customer.

1.2. System Operation

To fulfil the mentioned business processes and provide a safe, secure, and efficient electrical supply for all customers, DSOs have to operate the grid and the included physical assets. After providing an accessible grid for all customers, the operation is the basic for customer satisfaction with a high standard for service levels and customer engagement.

This can be achieved by efficient operation and keeping a balance in grid stability in this more and more complicating multidirectional system of electrical supply. The integration of variable **Renewable Energy Sources (V-RES) and Battery Energy Storage System (BESS)** is another big challenge regarding the operation of the energy system. The operation of the grid has to enable market participation and therefore the DSOs work as market facilitators and enablers for energy transition.

The system operation focusses on guaranteeing the stable supply of electricity to the costumers while, at the same time, assuring the maximisation of the integration of renewable production in the system **(70% of renewable energy sources are expected to be connected to the distribution grids by 2030)**. To ensure the proper operation of the grid, long and short-term grid forecasts are executed to optimise the actions and technical manoeuvres, which need to be carried closer to the time of energy delivery, to ensure the safe and within parameters supply of electricity.

Lastly, it is of utmost importance to guarantee the monitoring of the system both in real-time, and after the delivery of the energy, to detect unforeseen situation and adapt the processes to prevent them in the future. Naturally, all the processes encompassed within this group require a strong and mature technological basis, in terms computation and communication, but also the availability of data from all voltage levels (HV-MV-LV) is crucial to achieve a sufficient level of grid observability and therefore mitigate potential issues.

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1.3. System Planning

The planning of the distribution assesses the future requirements, which the grid shall follow to cope with the evolution of the overall system in terms of consumption and integration of production sources. In the future, the planning of the electricity grid will become more and more important. With the change from a unidirectional grid towards a multidirectional grid with decentral generation and complex loads the needs of the grid change.

Therefore, the planning of new grids but also the rebuilding of existing parts will become more challenging and needs to be supported with data from every possible source. The data-driven development can only be implemented when there is an organisational structure for a strategic asset management. The setup of such organisations, processes and responsibilities will be crucial for the sustainable and future oriented development of DSOs.

The planning of the future system needs is often made years in advance having into account long-term real and forecasted data from thousands, or even millions, of consumption and production points and current state of the grid assets and components. Analysis of grid future scenarios is complex because it is dependent on a variety of data from sources, which do not only include the system data, but also economic and social factors from the society.

1.4. Market and Customer Business Processes

In addition to plan, operate and maintain the distribution grid DSOs, in their role as market facilitators, need to ensure the relation with the system stakeholders and entities and the proper processes for the market to work.

Some of the activities often consist of the following:

- Grid connections
- Customer Contact
- Metering data points operation
- Metering data collection
- Metering data for billing
- Data for market processes
- IT/OT/Cybersecurity management

2. Technologies

These smart grid technologies have changed the conventional grid planning and operation problems in at least three main areas, primarily in the ability to

- Monitor or measure processes, communicate data back to operation centres, and often
- Respond automatically to adjust a process;
- Share data among devices and systems; and
- Process, analyse, and help operators access and apply the data coming from digital technologies throughout the grid. Some of the related problem space in smart grids include load forecasting (LF), power grid stability assessment, fault detection (FD), and smart grid security.

There is no well-defined and commonly accepted scope of what «smart" is and what it is not. It is generally understood that the smart grid encompasses the modernisation of the electric grid. Smart grid technologies allow the grid to become more flexible, interactive and enable it to provide real-time feedback. It incorporates technologies and services that facilitate intelligent monitoring, control, communication and self-healing technology.

Making grids smarter with energy intelligence creates new opportunities in a changing ecosystem. Smart grid technologies allow the grid to become more flexible, interactive and enable it to provide real-time feedback. It incorporates technologies and services that facilitate intelligent monitoring, control, communication, and self-healing technologies.

However, the smart grid represents a technical challenge that goes way beyond the simple addition of an information technology infrastructure on top of an electrotechnical infrastructure. Each device that is connected to a smart grid is, at the same time, an electrotechnical device and an intelligent node. Today's "connection" Standards need to address both aspects concurrently.

2.1. Artificial Intelligence

Artificial intelligence refers to a system that allows the performance of tasks that require a process of learning and considering new circumstances when solving a given problem, and that can, to varying degrees - depending on the configuration - act autonomously and interact with its environment.

From IT perspective, the term of artificial intelligence is usually used to describe computer systems that first analyse large amounts of data to, inter alia, categorise it and find repetition in it, and then make decisions based on this data. Such systems can "learn" from the analysed data, and continue such learning during their operation, whereby the way of making decisions is optimised and the data and knowledge is expanded.

A system operating in this way is referred to as so-called weak AI. Weak AI is the ability to act in a manner similar to human intelligence. Strong AI, on the other hand, is the ability to actually think, i.e. think in a non-simulated way. With this assumption, strong AI would probably be endowed with the awareness of its existence. All currently known AI solutions are in the weak AI group.

AI has wide reaching applications, from customer service solutions to asset management applications, to load prediction, and energy management solutions. One such example is the use of drone to inspect powerlines. Imagery can be taken and sent to a central hub, where the AI interface can provide recommendations to field staff for repair and maintenance based on imagery datapoints.

According to EC Expert group on artificial intelligence the term refers to systems designed by humans that, given a complex goal, act in the physical or digital world by perceiving their environment, interpreting the collected structured or unstructured data, reasoning on the knowledge derived from this data and deciding the best action(s) to take (according to pre-defined parameters) to achieve the given goal. AI systems can also be designed to learn to adapt their behaviour by analysing how the environment is affected by their previous actions.

Using advanced machine learning (ML) and deep learning (DL) algorithms as well as artificial neural networks (ANN), AI can handle huge amounts not only structured data but also unstructured or partly structured, from various sources. It can identify patterns and

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relationships between the data, but also attempt to predict possible scenarios while creating recommendations for decision makers managing a given process. Intelligent applications can also effectively make decisions autonomously and automatically, without human intervention.

Because of the rapid revolution of the modern power system, more distributed smart grid components—including smart metering infrastructure, communication infrastructure, distributed energy resources (DER), and electric vehicles (EVs)—are tightly integrated into power system by encompassing a huge electrical power network with the underlying communication system. Massive amounts of data are generated by those components to automate and improve the smart grid performance by supporting vast applications, such as

- Distributed Energy Management
- Forecasting
- Optimisation of network operations and activities
- Resource optimisation and strategic business decisions
- Predictive maintenance
- Maintenance and repair
- Security measurement
- Cyber security
- Adaptation/Anticipation to upcoming climate events
- Facilitating active consumers
- Product customisation and marketing measures
- Automating processes for metering, billing and general distribution

AI adapts through progressive learning algorithms, enabling data to perform programming. AI finds structure and regularities in the data so that the algorithm can gain skill: the algorithm becomes a classifier or predictor.

Back propagation is an AI technique that allows a model to be corrected through training and added data when the first answer is not right. These types of methods provide great value in forecasting processes, electricity demand, by incorporating external data, or data on changes in customer behaviour and changes in the number and type of distributed sources connected to the grid into historical data. Forecasting mechanisms combined with power network topology in a selected area saturated with distributed energy sources, charging stations for electric cars could effectively support the processes of managing electricity flow in the network, e.g. by performing automatic reconfiguration of the network or launching flexibility sources available in the selected area (along with automatic settlement of transactions carried out).

Because the communication network builds on power systems, very large volumes of data with high variability must be handled; this is still a challenge of smart grids.

Additionally, researchers are still working on the robustness, adaptiveness, and online processing of AI algorithms. Although numerous data-driven methods have been proposed to deal with the problems of smart grids, there are still many severe challenges, including the following:

- **Integration of renewable energy:** It presents several significant challenges due to the variability and unpredictability of renewable energy in which the power output can vary abruptly and frequently.
- **Big data fast storage and analysis:** Another significant challenge is how to continue improving the performance of storing and retrieving big smart grid data for AI applications robustly.
- **Explainability of AI algorithms:** Generally, AI algorithms have the black box problem, and they are not interpretable or explainable.
- **Limitations of AI algorithms**: The development of AI technologies greatly influences the deployment of AI to smart grid systems. However, every method limitation should be considered before applying them to the smart grid.

2.2. Proven cases of AI solutions by DSOs

2.2.1. Use of AI for Vegetation Management along power lines

Management of vegetation in power distribution is a mandatory operation to ensure a reliable supply of electricity and public safety. Vegetation Management practices not only help mitigate tree related outages by trimming back trees, underbrush, and vines, but also stump removal, conducting root management, and identifying 'danger trees' are all part of vegetation management operations.

Proper Vegetation Management is not only critical to operations, but also helps mitigate wildfire ignition related to power lines by removing the vegetation or slash from rights-of-way.

Trees that are too close to the power lines represent a significant hazard, putting human life and the environment in danger and are a leading cause for power outages. Each operator develops its own tree trimming management plan in compliance with legal requirements. Legacy approach of assets inspections is slow, resource intensive mostly with visual inspections and ground field surveys and often based on fixed annual cycles. DSOs, such as E.ON are using new digital vegetation management processes via cloud-based artificial intelligence and machine learning algorithms, making this process more efficient.

The AI helps to structure the data coming from a variety of data sources (*ground inspection*, *aerial imagery*, *drones*, *LiDAR*, *satellite*) and to extract insights by turning raw data into actionable intelligence based on status as well as on forecasts and predictions of vegetation (*tree species*, *weather data*, *historical patterns*, *etc*.). The use of AI enables to optimize planning of trimming on a condition-based approach built on predictive models which detect potential hazards before they occur.

2.2.2. Use of AI for Predictive Maintenance for network assets

Predictive Maintenance uses machine learning to predict if an asset of the electrical network is likely to fail in the near future. With this information, the asset replacement strategy is optimized and minimise the occurrence of failures. This helps spend the budget allocated by the Distribution System Operators (DSOs) for their asset replacement effectively. With algorithms, assets with the highest risk of failure are selected, on one hand, and components that would have the worst consequences in the case of failure, on the other hand.

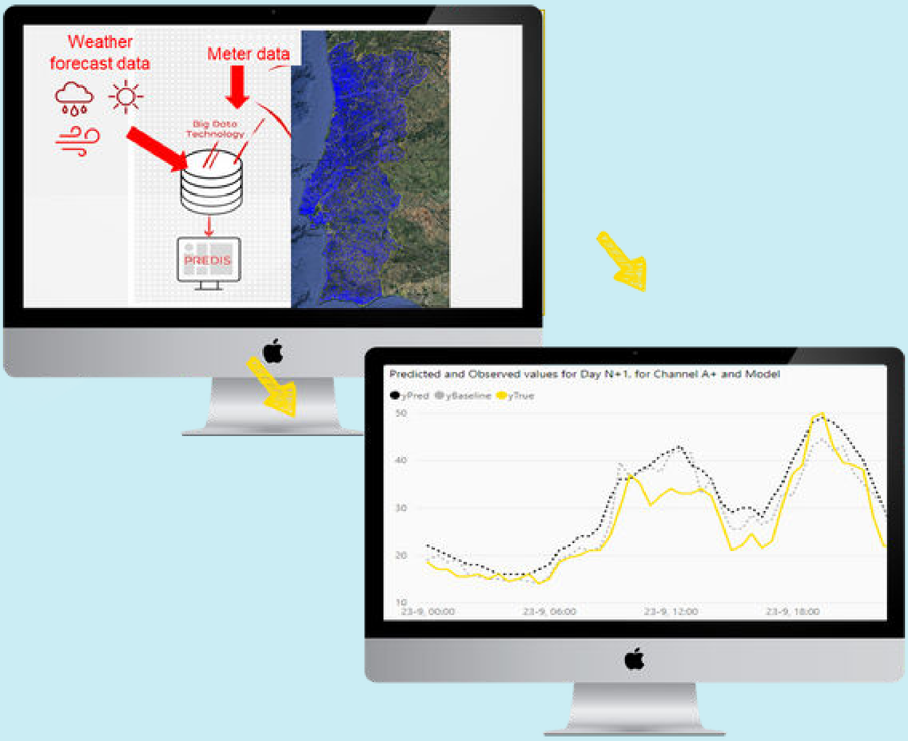
2.2.3. AI & ML Big Data forecast system for optimal grid operation - PREDIS

To operate its distribution network optimally, a Distribution System Operators (DSO) like E-REDES needs to perform optimal power flows (OPFs) on a regular basis. This problem is a classic task of energy systems, and its main goal is to allow the minimization of power losses and optimise other relevant variables. The recent developments in data analytics techniques created opportunities for further improvements: instead of using only past measurements and basing optimization studies on static moments, E-REDES can now use machine learning algorithms to produce forecasts of power load and generation for the next days, daily.

This way, it can be assured that the distribution network will operate close to the optimal point on the next days by:

- **Reducing energy losses in power lines:** Greater accuracy in the prediction of power flows in the network allows the Distributor to optimize the compensation of reactive power, reducing losses and, consequently, the costs for society in general.
- **Identifying more grid constraints in advance:** With the ability to estimate grid power flows for problems, it is possible to identify and correct the following days before they manifest.
- **Optimising the grid performance:** Greater integration of distributed generation and electric vehicles, which are key aspects of society's energy transition.

To achieve these objectives the system uses daily consumption and production data from 100.000 grid connection points from the HV and MV voltage levels, with a granularity of 30 minutes, being able to forecast the grid for the entire country. The objective is to continuously develop the system to integrate consumption and production data from all the 6 million connection points in Portugal, in order to obtain the most possible accurate forecasts.



Thus, PREDIS becomes an essential part of the revolution in network operation enabled by massive data processing and artificial intelligence technologies to facilitate the Energy Transition by being the basis for an accurate estimation of power flows in the distribution network.

Some positive results and outcomes from using the system were already identified and are the (1) Potential reduction in grid losses up to 14%, (2) Identified as essential in order to allow the usage of flexibility resources in the short-term network operation, and (3) the potential for deferral of network construction investments for 10 years or more.

2.3. Digital Twin technology

2.3.1. Application of the Digital Twin concept for a distribution network

A **Digital Twin** is a digital representation of a physical object, process, or service, or all of these elements together. The shape and range of the digital twin depends on company needs and ability to create perfect replica of reality. In other words, digital twin is artificial environment, a computer program that uses real world data to create simulations that can predict how a product or process will perform, which can be examined, altered, and tested without interacting with it in the real world and avoiding negative consequences. A digital twin is a virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity.

For a true digital twin to exist, the virtual model must be very precise and contain even the smallest elements. Virtual models based on data obtained from the existing, real power grids reduces the time and cost of designing new installations. Already at the design stage, the

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possibility of obtaining data on a specific unit using sensors is considered. Large, time-varying, and diverse datasets after processing with artificial intelligence algorithms can yield conclusions about future improvements and user-anticipated features.

Sophisticated engineering, analysis, and decision-support tools can be built into the digital twin. By going beyond mere IT/OT convergence, the integration of engineering information and technology enables DSOs to fully exploit their data—giving them new operational analytics and insights.

The consolidated, connected digital twin environment provides a unified view of a grid's current performance (*as well as a definitive record of its past performance*). A visual, intuitive user interface provides easy access to data. Open connectivity to disparate data and systems give access to what had been isolated legacy data and systems. All of this provides valuable insight into the health of the grid for proactive asset planning, management, and operations.

Digital-twin technologies in the power industry enable the development and maintenance of smart grids equipped with high-tech sensors and machine-learning models for increased efficiency and monitoring. Smart-grid meters enable energy service providers to make informed, strategic decisions and mitigate vulnerabilities and risk factors by disseminating up-to-date data. By combining cyber-physical systems, cloud computing, and intelligent industrial solutions, digital-twin technology becomes the basis for smart-grids deployment, renewable energy management, better integration, and efficient transmission.

The core benefit of why most DSOs started twinning their processes, products, and services via simulations is due to their efficiency. This technology will be able to anticipate how the product and process will perform through digital simulations and analysis. The accessibility of reliable and consistently updated information provides the assurance needed to make faster decisions and increase the speed of production to overtake competitors.

Digital twins allow DSOs to understand and model their grid's performance and plan for the entire lifecycle of grid assets. They enable controlled access to all the information utilities need to analyse and monitor what's happening across their entire grid operation and proactively mitigate the potential risks and threats. They enable sustainable grid reliability and resilience, intelligent grid design, increased project efficiency, and smooth integration of renewables to advance grid modernisation.

Depending on the level of advancement and complexity of the digital twin model, several levels of its maturity could be defined. The simplest ones include models which were created with the aim of having only information about a certain object and its parameters, however, in isolation from the environment in which it operates. Moreover, the most complex model, apart from the possibility of acquiring and analysing information and prediction, contains decision-making algorithms. The model, on the other hand, is based on many data also coming from the environment affecting the tested area.

Theoretically, **the following maturity levels of digital twin could be distinguished:**

- *Reporting* - this is the simplest level of DT development resulting only from the need of understanding how the observed object or resource behaves. Referring to the needs of DSO network, it may be the possibility of reporting on the status of sensors, e.g. responsible for measuring the load of the line (changes in the sag, temperature) in real time. Thanks to the collected data, it is possible to draw up a report on how the analysed object, which, apart from the electricity line, may be a substation, behaves. While such information is of great cognitive value, to give it an analytical value, another level of DT maturity needs to be activated.

- *Analysing* - having properly collected data about a given object, in this case about a line and a station/substation, if in the reports some disturbing trend or other problems affecting the change of network or supply parameters are visible, the analysis will allow finding an answer to the question why it happened. The next step in the evolution of the digital twin is to incorporate historical trend analysis into operational data to allow the user to understand the potential root causes of failure or performance degradation. Understanding why something happened is a big step up from finding out what happened. However, regardless of the knowledge obtained, further action is required and should seek to create mechanisms to predict and prevent unwanted occurrences

- *Predicting* - if the created digital twin can model and predict how a given energy line or, consequently, a whole station/substation will operate in the future, repairs can be better planned, predicting the necessary actions to be taken in advance to mitigate or eliminate damages (outages). However, at this stage the digital twin still only has data from OT systems. We can create working, useful behaviour prediction models, but they will only be based on analysis of operational parameters. If used properly, they will bring tangible benefits. To go further, we need to bridge the great divide between IT and OT. In addition, this is where the more complex solutions begin, aimed at striving for an ideal representation of a given section of the network and their behaviour depending on various factors and external data. Ideally, this is real-time data combined with information from high-quality forecasts.

- *Integrating* - here all the data from operations (device parameters, readings, measurements, line parameters, applicable standards, network loads) is integrated with external data, i.e. the needs of consumers, producers, their daily behaviour, but also other external factors such as weather or other environmental factors affecting network operation. Depending on the purposes for which the digital twins was created, at this stage it is also possible to connect data concerning, for example, development plans, investments, planned outages or identification of sources of flexibility that could increase the operational and economic efficiency of network operation.
  Such integration will also create opportunities to forecast future demand for parts and labour, develop cost models to optimally manage the business process rather than just assets, and even allow decisions to be made regarding future procurement.

Having digital twins defined at this level, it is possible to simulate, for example, various switchovers on the network to determine how the parameters in the station ultimately behave.
Proper mapping of the parameters of individual devices and sections of the network under existing (known/defined/calculated) external conditions can help in the selection of e.g. the right transformer, assuming that various devices/technologies will be connected (also EV, PV, storage).

For this purpose, advanced analytical methods based on ML, DL or AI are needed. At this stage, it is assumed that there may be many different digital twins in the company, which, to reach the highest level, combine into a single platform. By integrating data and models from the digital twins, the company will be ready to move towards analytics that recommend courses of action and interventions based on an integrated view of what matters most to the business. At this stage of digital twin development, a human makes the final decisions on actions.

- *Autonomous decisioning* - this is the highest form of digital twin. Systems capable of recommending actions will gradually be able to take more and more of these actions automatically. This is already happening in control systems around the world. In such an integrated and data-driven business, digital models of physical assets remain as important as ever. At this stage, visual representations of assets or fleets of assets can still be called digital twins. Alternatively, we can call the comprehensive visualisation of our entire business, from raw materials to sales contracts and all points in between, our new enterprise digital twin.

It is worth mention that collecting and storing data from a particular device (asset) or group of devices, stations or networks is not a digital twin. These are activities related to the different needs of the company, but they are not used dynamically in the process of mapping their behaviour.

The digitalization and creation of a digital twin of the distribution power grid enable the integration of virtual maps, images, and 3D models of real assets, network device data, and IoT sensor measurements into a single platform.

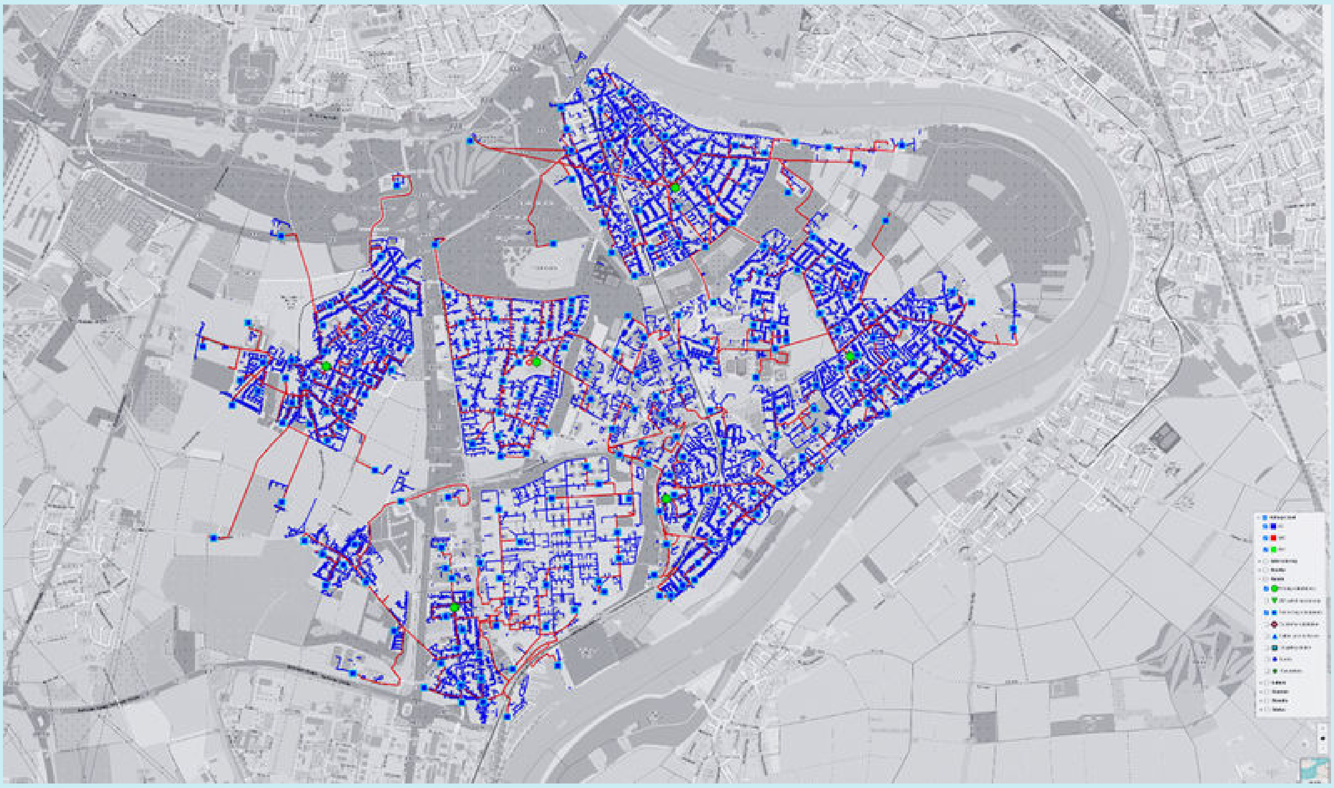
Power system operators in many cases use models that can be placed in one of the digital twin maturity levels. The most well-known example of a digital twin is a grid operation simulator (if created based on real part of the network). Depending on the sophistication of its functions and the needs for which it was developed, it can perform analyses, calculations and predict/simulate the behaviour of the network depending on the steps taken. If the simulated problem is solved using digital twin then it could be implemented in a real environment.

However, it is important to be aware that while existing and future IT tools allow the creation of models that will be able to simulate different solutions for the set range of needs, the essence of the implementation of these solutions should always be in line with the values it will bring to the power system and to its consumers. Above all, in line with the principle of economic and operational soundness.

2.3.2. Proven example

In 2021, E.ON acquired a majority stake in Envelio GmbH which is a German clean-tech company specialized in digital grid management. With its "Intelligent Grid Platform", power grid operators can set-up a digital twin of networks. They get full transparency about the grid to integrate additional DERs and manage efficiently connections requests. On top of that, the digital twin is basis for digitizing and automating grid planning and operation processes such as congestion management – a cornerstone for a fast and cost-efficient energy transition.

Figure 4. Detailed real-time insights into the power grids – from the substation level to the end consumer



3. Charting the way forward

The DSOs are undergoing consequential change driven by evolving customer and societal expectations around decarbonisation, decentralization and digitalisation or the "3Ds". These trends are having a transformative impact on the DSOs.

While electric grids are aging significantly, the energy transition is disrupting traditional DSOs requiring adapting to a new electricity paradigm: more and more intermittent and distributed renewables (DERs) and new customers' patterns. In addition, the urge of electrification from all sectors to replace fossil energies creates a higher dependency on electric infrastructure and requires strengthening the grid physical robustness and cybersecurity layers to ensure security of supply.

As "energy transition backbone", DSOs have no choice but to adapt and evolve, leading to massive development and modernisation investments to ensure that power stays reliable.

The DSOs digitalisation supports the virtualization of their operations (technical and economical) so that the actual location of knowledge, data, computations, becomes independent from the place where knowledge data and computations are originated or performed.

Evolving new technologies such as robust fiber and wireless networks, artificial intelligence, data analytics, remote sensors, automation, and drones are creating opportunities to collect real-time high-quality data, understand it, gain strategic insights, and make decisions with automated responsive actions.

Traditionally, the digital dimension of DSOs has been associated with smart meters, which allow households to control their energy bill by prioritising consumption when power is cheapest, usually at night. Artificial intelligence (AI) is helping DSOs to be more accurate of energy demand forecasts and bring big energy savings on a system-wide level.

Digitalisation is all about the ability of making the right operational decisions based on reliable data. This approach to DSOs has become the new foundation for securing the successful transition to cleaner, decentralised energy.

DSOs of the future will have to manage the infrastructure required to produce and distribute the clean energy, play a fundamental role in ensuring that we can execute on these goals successfully.