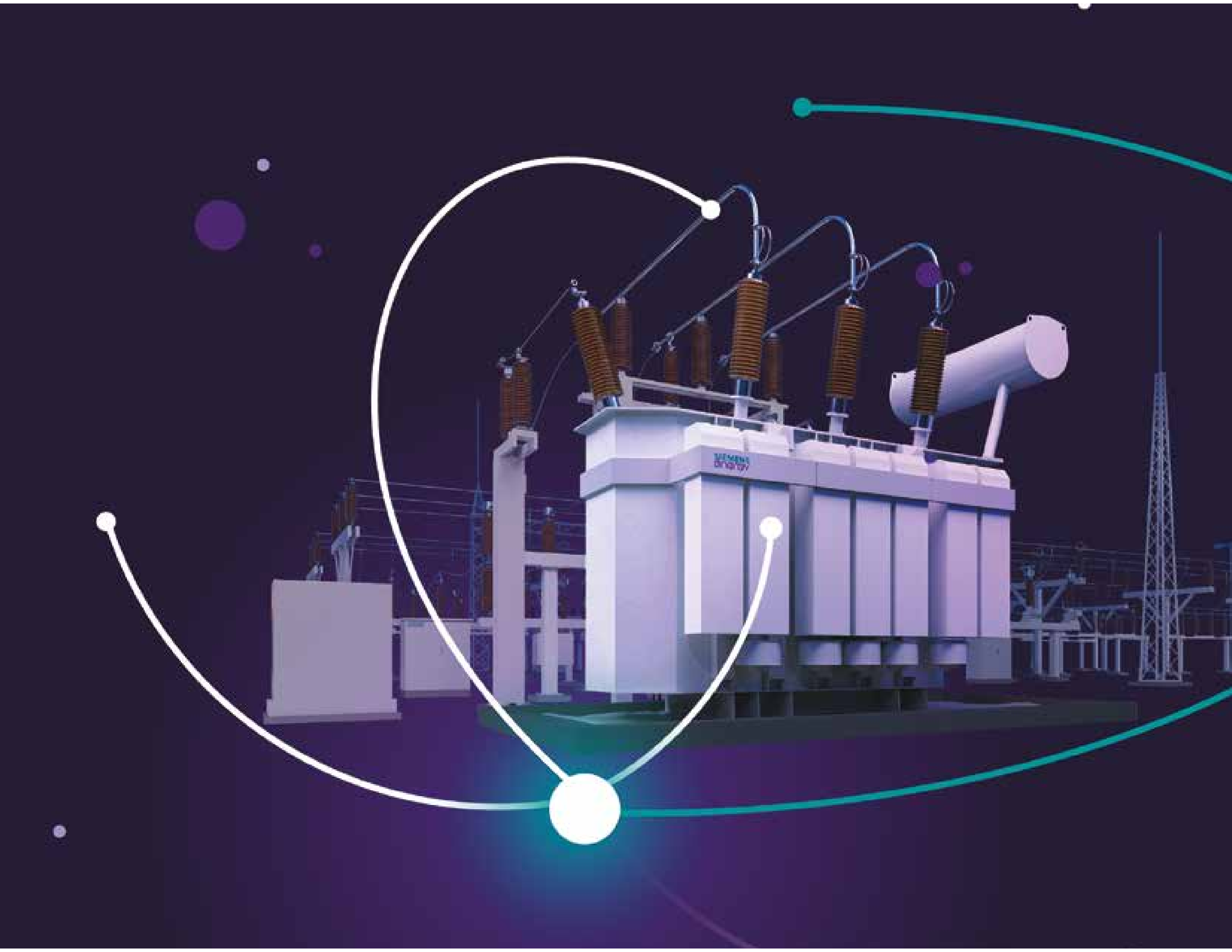


## ABSTRACT

This paper describes how this digital revolution can work together with traditional electrical grid infrastructures and how it beneficially addresses the system operator's needs. It addresses cloud-based technologies and their use for monitoring, data analysis, the use of the digital twins and more.



## KEYWORDS

cloud computing, digitalisation, digital twins, monitoring, power-grid


# The next generation of energy transmission

## The beneficial role of digitalisation in power grids

**Network operators are investing in advanced monitoring and data acquisition systems to ensure effective use of the equipment and increased reliability**

## Introduction

The electrical transmission and distribution (T&D) market is quickly transitioning to new technologies. This trend includes incorporating different power generation methods, serving more people, operating in a fast and effective way, reducing losses and increasing overall efficiency. Additionally, businesses are stressing the importance of continuity of the power supply. Any loss of power, however brief, takes a huge toll on the bottom line. Reducing failures, increasing productivity, and maximising resources are also priorities.

These factors lead to an exponential increase in the complexity of energy transmission systems. On the one hand, operators are working to maximise profits by increasing productivity (revenue). On the other, they are reducing expenses (loss of earnings, penalties, failure-related costs). To meet these objectives, operators are now investing in advanced monitoring and data acquisition systems to ensure effective use of the equipment and increased reliability. They are investing in intelligent systems, such as smart and digital grids, that can optimally manage the flow of energy.

In this context, the digital 4.0 revolution is helping to meet and solve the requirements of T&D systems operators. Today, modern substations continuously generate and remotely transfer data to a control room. They also provide control of installed assets in real-time. These substations can assess the overall status of these assets and make decisions on their short-term performance or even identify the need to replace them. The most attractive and demanding challenge is to combine an analogue electrical transmission with a digital system. In the past, these systems were merged with great difficulty. The first generation of sensors was simply not strong enough against the electromagnetic environment of the high voltage substations. However, the rapid advancement in robust, reliable, and cost-effective sensors is paving the way for the digital transition of the power transmission industry.

This paper describes how this digital revolution can work together with traditional electrical grid infrastructures and how it beneficially addresses the system operator's needs.

## Review of the current substation control limitation and future digital approach

Transmission grids are traditionally controlled via SCADA systems with very robust and complex control systems architectures for high-level supervisory management. This allows users to monitor their stations and send remote commands if needed. Over the years, the success of SCADA has been very well documented in many substations.

SCADA's big advantage, i.e. its complex and hierarchical structure, is also its biggest constraint. SCADA systems are not agile and do not allow users to perform elaborate analytical evaluations if requirements go beyond PLCs (programmable logic controllers) or PIDs (programmable integrated device control). This does not mean that SCADA is not suitable for transmission systems monitoring. However, as stated above, today's networks require more complex and reliable controlling algorithms, and sometimes an agile architecture could be the right choice.

A possible approach to augment the traditional SCADA architecture is shown in Fig. 1. All assets of a high voltage substation can transmit data to a cloud-based platform that represents a parallel information channel to the SCADA system in real-time. On this cloud-based platform, data is analysed by complex algorithms. As a result, conventional control, protection philosophy and a more agile information channel with a cloud platform for faster analytics can be combined.

**Today's networks require more complex and reliable controlling algorithms, and sometimes an agile architecture could be the right choice**

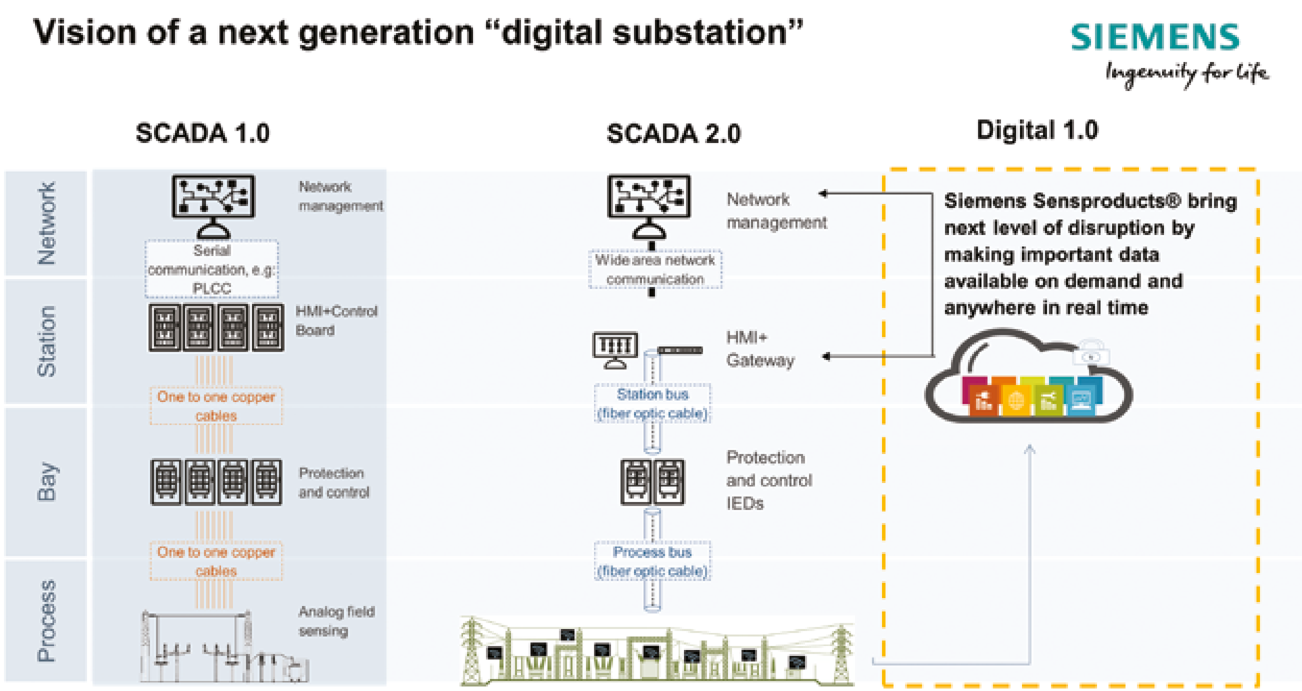


Figure 1. Monitoring architecture of transmission substations evolution, from left to right, as exemplified by Sensproducts, connective transmission products by Siemens Energy

## Cloud-based platform can be integrated with existing SCADA and PID architectures to perform complex analyses and calculations required for better managing the grid

This philosophy starts with a holistic and integrated vision. The reliability of data interpretation is improved if the data is collected from multiple (and not single) sources. Consequently, decisions can be made with more confidence and in less time with more rational and trustworthy data sources.

A major advantage of this edge computing-based approach is a rapid interpretation of the status data that is much faster than with legacy systems. Additionally, more complex data handling can be accomplished when PLCs or PIDs controllers in typical SCADA systems are used. Thus, the analytics are more accurate, computations faster and more reliable, and response times lower since digital signal processing and interpreting algorithms are getting faster every year. Any cybersecurity concerns are addressed by applying the latest state-of-the-art security standards for transferring and analysing the status data.

Many distribution systems operators (DSOs) worldwide do not use complex SCADA or distribution management systems (DMS). Failures in their equipment are often not visible to the DSO in a timely manner. It often happens with pole-mounted distributed transformers, see Fig. 2, that are very old and when they break-down utilities cannot detect where the point of failure occurred.

GPS information can be easily integrated into the cloud-platform approach. This makes it very helpful for DSOs who wish to improve their performance in locating failures, even without additional sensor data. Additional sensors could help prevent events that may lead to equipment fires, causing forest or vegetation fires or catastrophic failures. Therefore, having all assets cloud-connected in the first layer could be crucial for distribution networks and ensure continuous service of the networks.

However, the breakthrough benefit of this innovative approach is related to the possibility of integrating operational information in a dynamic way. The key is to collect all the important operational information from the substation into a cloud platform and then merge it with other information from the protection and control system. Fast data analytics lead to enhanced substation reliability and increased workforce productivity using easy-to-navigate "apps", offering all-important asset information in near real-time, anywhere, on-demand and with clear handling instructions.

Let us imagine for a moment that we would like to make a decision based on data related to the residual life of the substation equipment. Before going into details, it is important to point out again that in this paper it is not intended for the cloud-related architecture to replace any monitoring relay or safety device usage but to supply additional and parallel information to support informed decisions.

As substation equipment ages, utilities must decide to either invest in new equipment or extend the life of the existing assets. Earlier generation equipment was designed with assumptions that are not necessarily valid today because the working boundaries of power grids have recently changed a great deal. With more real-time operational data available from the units, it is possible to develop very complex algorithms to extract useful information and maximise their equipment usage and life. Furthermore, cloud-connected sensors easily enable the collection of all the data from different sources for faster analysis in an integrated and more reliable system.

A connected substation provides global information and more analytics than single, unconnected sources of information, thus facilitating faster and accurate decisions under dynamic grid conditions.

A simple example of this approach can be taken from a performance analysis of high voltage bushings in AC networks. These bushings are among the most important elements in power transformers since they are the most exposed and stressed components. An analysis of the data from the bushing is quite complicated due to the difficulty of accessing the bushing (usually only the test / voltage tap is available for measurements) and the interpretation of the very limited data. This obviously results in a low level of confidence in the bushing monitoring systems.

By expanding this to an integrated system, we can measure the line voltage from the voltage transformer (VT), and correlate with the leakage current measured from the test / voltage tap on the bushing. The bushing impedance can thus be obtained with higher accuracy, identifying a failure mode more accurately by involving bushing capacitance and / or dissipation factors. In addition, the load current from the current transformers (CTs) and the external ambient temperature may be used to understand whether the bushing can be overloaded or not. Further, the historical database of the substation can help determine the residual life of the asset itself, taking previous load conditions and especially stress levels into account.

All this information was not available in the past (or at least not in such a simple, fast and easy way). Now, it allows for quick and informed decisions, thereby optimising substation OPEX (operating expenditure) and CAPEX (capital expenditure). The above example proves that digitalisation facilitates not only diagnostic decisions but also operational decisions. In a world where more and more functionalities and power are required from the existing grid, system operators must maximise their equipment utilisation without affecting the overall lifespan quality. This topic is usually considered as overload possibilities of the general equipment (e.g. power transformers or GIS substations) to fulfil peak load.

Overloading may be allowed for the power equipment and is traditionally addressed by overloading guides and curves provided by the IEC, IEEE or similar technical guides, based on the past experiences and industry research. Such an approach is not optimal because it does not take specific operation conditions into account. The only way to address the problem is considering the Laplace's model, i.e. using an electrothermal model in operating conditions.

If the ambient conditions are unknown, it is impossible to understand or predict how equipment handles stresses related to overload. However, if we have the required ambient and equipment information, we can calculate and predict how the unit will react to a particular transient event. This feature is known as a "digital twin" since the equipment model acts as a twin of a real unit and can be used on a cloud platform to simulate the behaviour during real-life overload events.

**A connected substation provides global information and more analytics than single, unconnected sources of information, thus facilitating faster and accurate decisions under dynamic grid conditions**

An example of the benefits of a digital twin is shown in Fig. 3. It illustrates a comparison of a transformer load cycle according to the transformer specification and general guideline, on the left, to a predicted transformer load cycle based on digital twin operation functionality using retrospective transformer operation data, on the right. As per general guideline, the transformer operation condition is limited, i.e. an overload of 1.25 p.u. is permitted for seven hours; afterwards, the transformer must be operated at 0.6 p.u. for 23 hours in order to keep the loss of life at the nominal figure. A permanent maximum ambient temperature is defined and used for transformer load and temperature design. However, in most cases, the load is less than 1.0 p.u. The ambient temperature fluctuates rather than being constant, and most likely, it is below the specified maximum ambient. The picture on the right is an example of

Figure 2. Example of faults in pole-mounted distribution transformers

**The historical database of the substation can help determine the residual life of the asset itself, taking previous load conditions and especially stress levels into account**

a more realistic case and the enhanced load capability obtained with the usage of the transformer digital twin. The upper picture on the right shows the real ambient temperature (green line) versus the specified maximum ambient temperature. The right bottom picture shows the real load (green line before t = 0 min) and the predicted load by digital twin operation (green line for t > 0 min). The load capability is enhanced by approximately 28 per cent for a GSU 588 MVA transformer by using the digital twin operation load prediction since both ambient temperature and the previous load were lower than the standard value assumed by the general guidance. This result is not surprising: the IEEE guidance is suggesting a quick and not so precise tool to address the overloading topic, while the digital twin is relying on far more data, which are therefore able to generate more precise and accurate results. The benefits of the digital twin are thus related and connected to the richness of available data for the elaboration.

This is a big step towards productivity optimisation. It is the first time that overload is driven by a real condition rather than general assumptions. As a result, the substation operator can maximise the performance and productivity of the asset.

## Conclusions and future work

In this paper, we have outlined the current approach of power grid management and explored the benefits of a digital layer applied to this environment. The biggest benefit of the digital layer is that it provides the basis for overcoming limitations and complexity of the current control systems for transmission networks and it addresses simple monitoring needs of the system operators, without replacing the current control system philosophy. Rather, it serves as a parallel source of information.

Digitalisation is disrupting traditional monitoring architecture of transmission networks and can be used to easily cross-correlate the data of different assets. The data can be interpreted on a cloud platform, with a complex data management structure providing a faster picture of the actual status of the assets while enabling system operators to make faster and more rational decisions and simplify OPEX and CAPEX evaluations.

The increasing and ever-evolving network complexity raises the bar for transmission system operators to guarantee a high and safe level of power continuity and to maximise the productivity of their systems. Well aware of the advantages of digitalisation, Siemens launched Sensproducts, innovative transmission products operating as real IoT solutions, performing auto-diagnostics and communicating with the end-user to provide life estimation or predict overload capabilities of their equipment.

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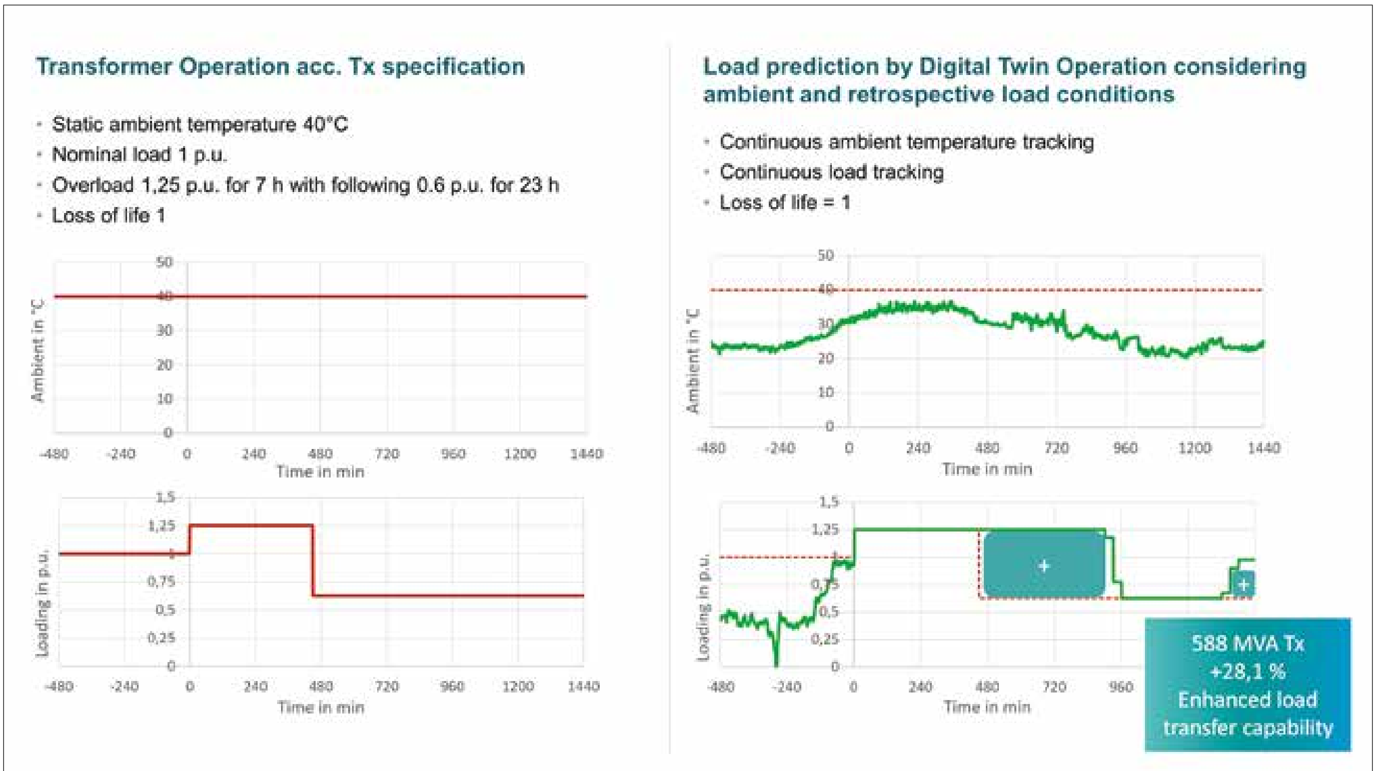


Figure 3. Digital twin operation: Performance increase by temporary overload optimisation

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**Digitalisation allows utilisation of digital twins - a model created from design and manufacturing data that acts as a replica of the real unit, and various real-life scenarios can be simulated on a cloud platform to predict its behaviour**

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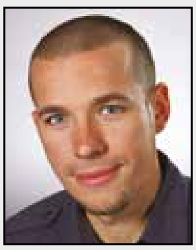

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