Redefining transformers manufacturing and operational excellence in the digital age, Hitachi Energy's perspective


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This digital transformation isn't just about convenience; it's about enhancing our capabilities and expanding our horizons

We are living today in a world where technology and data are integral to our daily lives. This rapidly expanding era of digitalization has revolutionized the ways we communicate, work, and even enjoy ourselves. From smartphones to connected cars to automated homes, our reliance on digital tools and platforms continues to grow, shaping a society that is more informed than ever before and benefits from data in many aspects of life.

Think about how digitalization has changed our daily activities. Now, we can search for information instantly, chat with people worldwide in real-time, and automate everyday tasks to save time and effort. This digital transformation isn't just about convenience; it's about enhancing our capabilities and expanding our horizons, whether it's through online education, telemedicine, or remote work.

In the energy sector, digitalization is changing the way we manage and consume energy, and it is a contributor to the clean energy transition towards electrification. Advanced technologies have made electricity management far more efficient, enhancing grid flexibility, resilience, and stability. Digitalization complements all operations related to designing, planning, and operating power systems. For instance, it leverages advanced control systems and power electronics to support the integration of renewable energy sources, ensuring supply and demand are balanced to maintain optimal grid performance.

If we think about transformers, we have used sensors and monitoring systems for many years now to enhance their performance and operational life. This has evolved from sensors and monitoring to digitalization with the advent of modern Asset Performance Management (APM) software, edge computing, cloud technologies, advanced algorithms, and machine learning.

All those advancements are enabling real-time monitoring, predictive maintenance, and data-driven decision-making. However, this volume of data presents different challenges, for example those

associated with cybersecurity, privacy, and data integrity. Machine learning algorithms and artificial intelligence offer promising avenues for exploring the hidden patterns and correlations within these datasets. Techniques such as multivariate regressions, neural networks, and decision trees can help us to analyze both historical and real-time data to identify anomalies, predict potential failures and optimize maintenance schedules, thereby reducing downtime and extending the life of transformers.

But it is not about the operational life only; digitalization is being applied across the entire transformers value chain, extending far beyond operation, maintenance, and service life. The integration of modern digital tools and artificial intelligence is transforming engineering and design, making transformers more efficient and reliable.

In the manufacturing domain, the integration of digital tools and smart technologies into transformers production streamlines production processes, ensures quality control, reduces lead times and adds long-term value through data-driven operational enhancements.

This article provides insights from Hitachi Energy into this crucial area, explaining where we stand today and the future direction as we are heading to enhance the manufacturing and operational excellence of transformers through digitalization.

Optimizing production

Digitalization offers opportunities to streamline and refine production processes. In transformer manufacturing, precision is crucial, as even minor imperfections can lead to significant performance issues down the line.

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Advanced analytics, automation, and predictive modeling in the production process are helping to achieve a higher level of precision and reduce the risk of defects.

During manufacturing, data related to processes includes metrics on machine performance, cycle times, material flow rates, energy consumption, and even environmental conditions like temperature and humidity that may affect manufacturing precision. By compiling this real-time information, manufacturers create a *holistic view of the entire production process*, allowing for pinpointing inefficiencies and understanding how each piece of equipment interacts with others in the process flow.

Digital twins—virtual replicas of physical assets— can simulate the entire lifecycle of a transformer from design to operation. This approach allows engineers to model different operational scenarios, check for weak points, and optimize the design before production begins, saving time and reducing costs associated with physical prototypes.

This digital modeling enables manufacturers to gain a precise and dynamic view of each component of the production line, from raw material inputs to the final assembly. By leveraging this data, manufacturers can identify and address bottlenecks, optimize resource utilization, and ultimately enhance output.

The use of digital twins combined with the theory of constraints is allowing the identification of bottlenecks in processes and equipment, revealing where delays or downtimes most frequently occur and helping to address those inefficiencies that may limit the overall output.

For example, if the winding stage of transformer manufacturing is consistently having a larger cycle than other stages, the digital twin will highlight this as a bottleneck. By prioritizing this stage for optimization, manufacturers can apply targeted interventions, such as new or upgrading equipment, adjusting labor allocation, or refining process parameters to improve efficiency specifically at this constraint. The continuous feedback from the digital twin enables rapid testing and adjustment of these interventions, ensuring the changes are genuinely impactful.

Ensuring quality and compliance

Quality control is a top priority for Hitachi Energy, and digitalization is increasingly contributing to enhancing quality assurance and how it is conducted.

Sensors, IoT devices, and machine learning algorithms now provide detailed monitoring and data analysis at each stage of production. Sensors embedded in equipment continuously measure variables like temperature, humidity, and vibrations, which are critical factors affecting transformer durability and performance.

Machine learning algorithms can process this data in real-time, detecting anomalies and alerting technicians to potential quality issues before they escalate. For Hitachi Energy, integrating these technologies into the production line ensures each transformer meets regulatory standards and quality requirements, minimizing the likelihood of post-installation failures.

Moreover, digital quality control systems help manufacturers meet increasingly stringent industry standards and environmental regulations. By continuously monitoring emissions, energy consumption, and material usage throughout the production process, manufacturers can identify inefficiencies and reduce waste. This approach supports compliance with environmental standards and aligns with Hitachi Energy's commitment to sustainability, as digitalized production systems enable a more responsible use of resources.

Digitalization also guarantees full product traceability by recording every stage of the manufacturing process, from raw

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material input to final assembly, allowing manufacturers to track and verify each component's journey. This end-to-end traceability secures the highest quality level standards, enabling immediate identification and rectification of any deviations, thereby enhancing quality control and compliance with industry regulations.

Digital-friendly work environment

Hitachi Energy is upgrading transformer factories with more modern setups, which greatly enhance the work environment and make it also more attractive for employees.

A digital-friendly environment is instrumental in attracting and retaining new employees. Transformer manufacturing requires a highly skilled workforce but also the use of multiple documentation, drawings, and the completion of inspection cards and quality checks. New employees go through extensive and specialized training. With the aid of digital tools such as a user-friendly manufacturing execution system (MES) connected to a document repository, access to essential information like project documentation, 3D drawings, and process instructions is now easier.

With the implementation of fully integrated IT systems, we can now provide operators with the necessary information at the right time in an easily accessible and user-friendly form, precisely at the point of use.

This transformation reduces reliance on operator experience and shortens training duration significantly. Furthermore, augmented reality tools can assist in operator training and offer remote expert support when needed, thereby providing additional guidance from any location. This allows us to provide robust global support for all production sites, ensuring that regardless of the manufacturing location, products always meet the same quality standards.

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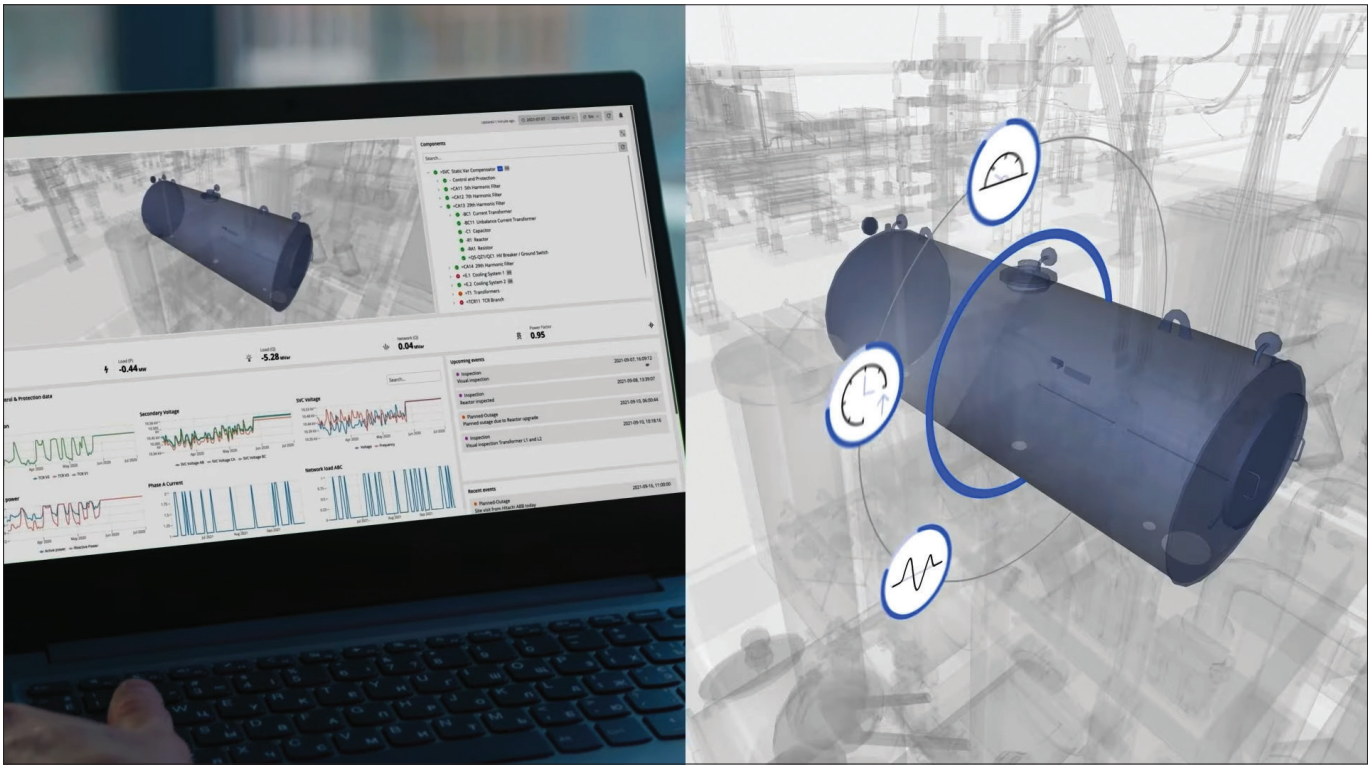
Paperless factory

A positive outcome of driving digitalization is that factories are becoming paperless environments. This change not only helps achieve our sustainability goals but also ensures that only the latest and most updated revisions of critical documents are available.



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Additionally, any data collected is easily accessible for analytical purposes, whether it be quality measurement or the status of completed tasks. These crucial pieces of information are readily available for analysis, facilitating quick response when necessary.

Remote factory inspections and acceptance tests

Remote manufacturing inspections and remote factory acceptance tests (FAT) have become increasingly important in the transformer industry. These processes leverage digital technology to ensure that manufacturing plans are maintained and delivery dates are met, and make it easier for inspectors and customers to follow the manufacturing process.

Remote FATs allow for virtual, real-time testing, which is both time-efficient and cost-effective. This approach involves interactive, two-way communication with the test engineering team to discuss and clarify various aspects of the tests, ensuring that all relevant production steps are performed and streamed live.

One of the key benefits of remote FATs is the ability to witness testing results in real-time. This is achieved through a multi-camera setup that provides views of the test room and test results screens. The ability to split the screen so that visuals from two sources can be viewed simultaneously enhances the clarity and comprehensiveness of the testing process. This setup allows for instant viewing of test results, which are also recorded and accessible for future reference.

The process includes all testing, such as loss measurement, heat run, impulse and partial discharges, all streamed live with full resolution, with results available as the process proceeds with the final test reports sent by email.

Remote manufacturing inspections and FATs provide a more convenient and efficient way for customers to witness and verify the quality of the transformers being produced, with other benefits like time and cost savings and reduced emissions associated with travel, enhanced safety, and improved efficiency.

Stepping into tomorrow: The future of digitalized manufacturing

Digitalization is redefining transformer manufacturing by enabling a highly responsive, data-driven approach to production. With advanced digital tools, manufacturers are optimizing processes and dynamically adjusting production schedules, reallocating resources, and implementing process improvements based on real-time demand forecasts. This adaptability allows manufacturers to simulate and evaluate various configurations or production parameters without disrupting actual operations, providing a powerful framework for anticipating market needs and scaling efficiently.

As digitalization continues to advance, transformer manufacturers will gain even greater agility and precision, ensuring they meet evolving demands with minimal downtime, optimized resources, and maximized output, that have a positive impact in quality, flexibility, operational efficiency and overall customer satisfaction.