

Digital Twin
for power systems
in an all-electric world



We are living in a world where change is everywhere ...

Data centers, wind parks, or industrial parks – they all rely on a secure and reliable power grid. For example, a failed medium-voltage cable connection can lead to revenue loss for wind parks, while power outages in data centers can prompt industrial customers to reassess their IT strategies in respect to cloud applications. To avoid such events in a heavily used electrical infrastructure, smart monitoring solutions can bring massive benefits in an all-electric society [1]. They keep you, as energy operators, transmission system operators, distribution system operators, data centers, industry and infrastructure customers, in control of your system, and help you with your power system's requirements.

System reliability is improved due to 24/7 early fault detection.

Asset lifetime optimized by prolonging an assets' lifetime.

Emission reduction targets met with a path to net zero by providing transparency.

Grid capacity expanded, enabling new fast-growing industries, thanks to higher asset utilization.

// Capacity addition of photovoltaic may increase by a factor of four this decade. [2]

Immediate action is required because grid operators worldwide will face more challenges in the next few years than they faced over the past few decades. Challenges include:

Connecting new inverter-controlled equipment: Spanning heat pumps, superchargers and electrolyzers.

The switch to a new, greener power system: New ways to operate grids can lead to power quality distortions.

Climate change: Increasing probability of extreme weather events and the impact on the asset.

Cyber-attacks: Attacks are becoming more challenging with growing system complexity.

System lifecycle management: Becomes a challenge with changing regulations and laws such as emission tracking.

Performance degradation: Older assets have a much higher fault probability.

Therefore, a resilient, sustainable, and adaptable grid is essential to address these issues now and in the future.

The all-electric world ...

- RES: Renewable Energy Source
- Data center
- Industry

... changes your requirements ...

- Reliability: 24h/7d
- Emissions: Net Zero
- Expansion & Growth
- Asset Lifetime: 30 years +

... and presents you with challenges.

- New grid participants
- Switch to a new system
- Climate Change
- Cyber-attacks
- System lifecycle management
- Performance degradation

... and where **new solutions are a must, not an option!**

The general challenges highlighted in the previous chapter can result in very specific issues, affecting your daily operation. Here we present our vision on how to solve these challenges and enable your future success in the all-electric world.

Your Challenges

Complexity: A linear extrapolation based on previous experience cannot work in a fast-changing non-linear environment.

Workforce: As the grid capacity increases, the upcoming retirement of seasoned experts in the electricity sector poses a workforce challenge.

Power Quality: Power quality issues caused by new grid participants can lead to undetected asset degradation and unexpected/unwanted system disturbance.

Carbon Footprint: Information to both optimize the lifetime of an asset and its carbon footprint in the use phase is required.

Knowing the limits: Network operators will be compelled to infer the state of networks to circumvent or address congestion scenarios. Conventional state estimation methods, which rely on extensive measurements and sensor deployment, are not feasible.



Electricity demand from data centers could double from 2022 to 2026. ^[3]

Our Vision

Leveraging existing know-how is the starting point. This know-how is embedded in the physical models of OEMs to design grid assets, ready to be used as a foundation for advanced physics models and physics-enhanced AI to be applied during operations.

With the right tools, **transparency and guidance** is provided to new colleagues, while the effort to maintain additional data points is minimized following a smart data approach.

Focusing on both the asset and its actual operational condition as part of the power grid can provide a true benefit. Fully evaluating a power quality signature requires both a knowledge of the grid e.g., how often could this issue occur, and the asset e.g., how severe is the impact on the asset?

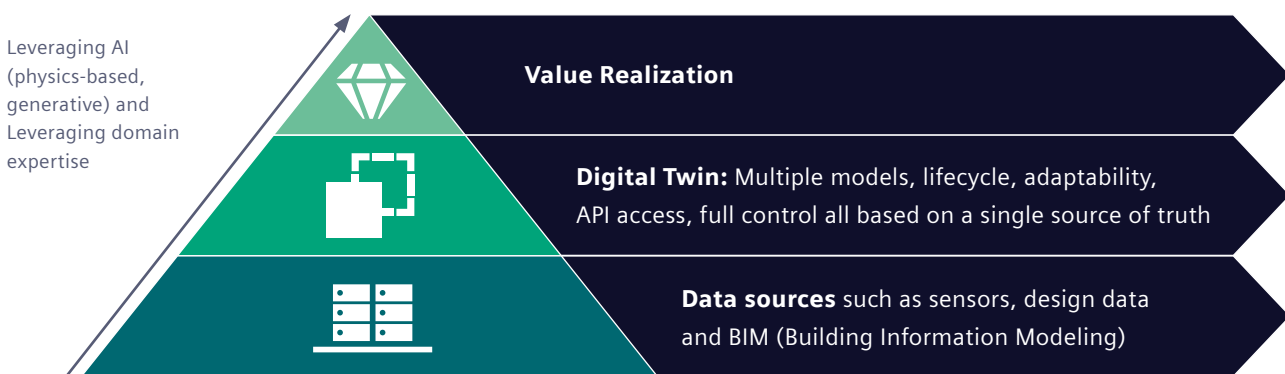
Full transparency and the analysis of different, future scenarios are enabled by suitable models and a unified platform to provide the complete overview.

Minimizing the need for new sensors is a key requirement in many applications. This can be achieved by leveraging prediction and self-learning models, supported by knowledge of the equipment and of the power grid.

To handle all these different challenges, a new technological approach is required: The Digital Twin. In simple terms, a Digital Twin provides a single source of truth for an asset's actual and accurate state. Being an asset's digital representation, it is the cornerstone for combining the real and digital worlds. We will elaborate on this idea in the upcoming chapters and when discussing a Digital Twin in the subsequent sections, we specifically mean a Digital Twin representing assets and systems in power grids: The Digital Twin for power systems.

Empowering your power system with a Digital Twin for your success

Success factors of a Digital Twin



The original term “Digital Twin” is not a new concept; the origins being presented in 2002 [4]. Siemens as a technology leader has outlined its importance for several years [5]. The next section will discuss the key aspects of a Digital Twin:

Single Source of Truth: The Digital Twin eliminates the need for manual data transfers between data silos together with discrepancies and inconsistencies. The single source of truth creates the foundation for the complete Digital Twin. [6]

Multiple Models: A Digital Twin leverages the expertise of professionals, the knowledge in physical models, and data through data-driven approaches. The latter includes the whole spectrum from deterministic behavioral models over physics-based and -constrained artificial intelligence (AI) models to models based upon generative AI. A Digital Twin uses what is already available. For example, manufacturers calculate and then validate, eventually in a type test, parameters like the ohmic losses of your electrical asset, providing valuable information for certain models and specific applications.

Lifecycle: The Digital Twin forms a cyber physical system with your asset, a combination of real or physical components, and cyber or digital elements. The Digital Twin represents the digital part of your asset. As the physical part covers the entire lifecycle of the asset, so must the digital part.

Combining and enriching data along the whole lifecycle maximizes the value add through each lifecycle stage by the Digital Twin.

Adaptability: The Digital Twin can easily incorporate technological advancements, system upgrades, and shifts in operational requirements. With this adaptability and representation of the true state of an asset, the Digital Twin offers a predictive capability that was previously unknown, a true benefit of coupling a model and a real asset.

API Access: As the twinned asset interacts with other assets, the Digital Twin replicates this interaction for seamless integration and data sharing, being in sync via an interface, in the best case an API (Application Programming Interface). An API, such as a REST API, ensures data exchange across different manufacturers and application domains.

Full Control: Detailed information is available via asset transparency to suggest tailored solutions, solving the underlying root-cause of a problem. While such a Digital Twin can recommend the best possible action and provide a schedule, the decision to dispatch a technician is still ultimately made by the responsible human. Furthermore, the Digital Twin should not be a black box, but be able to explain the phenomena.

The benefits of a Digital Twin

Value by combining the real and digital worlds



A tangible value-add is generated by applying the Digital Twin. These benefits include:



Higher utilization and higher availability:

The Digital Twin enables concepts such as virtual sensing [7], providing deep insights into the asset's performance. For example, a partial discharge sensor or a temperature sensor can be utilized, together with additional data like temperature and location, to provide further insights into an asset's true condition. The Digital Twin interprets this data based on multiple underlying models and presents the resulting opportunities. Despite a higher utilization of the asset (lower CAPEX), the advantages of condition-based maintenance (less OPEX) remain.



Maximizing each measurement's value:

The Digital Twin can approximate network connection point voltages without relying on local real-time measurements, reducing the instrumentation requirements for low-voltage networks. A solitary measurement at the secondary substation may suffice for network monitoring purposes, providing a cost-effective alternative to traditional methods, aligning with the concept of smart data.



Updated and adaptive insights: The Digital Twin serves as the foundation for a strategic outlook, with a continuous transparency to track your improvements against real dynamic data. For CO₂ as an example, this includes the operational emissions as well as for instance spare parts management, allowing for an optimized service scheduling, prolonging the life of old assets and avoiding CO₂ emissions associated with the purchase of new ones. Better decisions are enabled earlier.

Optimization of maintenance: The Digital Twin combines sensor information, asset-specific questionnaires, and commonly available information like weather conditions, following the single source of truth approach. With this information further analyses can be done based on physics-based and/or data-driven models, for example resulting in an advanced Health Index, which provides a numerical value representing overall asset health, the foundation for advanced maintenance planning.

Transparency and scenario planning: The basis for every sustainability strategy is to define your targets (e.g. a net zero target for scopes 1 and 2 by 2030), and then to baseline your footprint. With sufficient transparency, you can define actions on the main emissions contributors and track their impact to ensure you are in line with your targets. This transparency also serves as the foundation for a ISO50001 certified energy management system, fulfilling the need— e.g., caused by the European Energy Efficiency Directive (EED) – to do an energy audit.

Scalability and flexibility: Thorough testing at all levels ensures smooth operations throughout the lifecycle. End-to-end testing supports the user's growth without causing integration issues, enabling an efficient roll-out to all assets. To connect all assets, APIs to third party applications e.g. transformer and motor monitoring, must be available, aligning with the vision of Siemens Xcelerator.



Electrification X

A solution that combines the real and digital worlds

Electrification X combines the real and digital worlds in the Xcelerator IoT Software as a Service (SaaS) offering, designed to master the challenges of energy transition.

It helps renewable energy operators, transmission system operators (TSOs), distribution system operators (DSOs), data centers, industries and infrastructure customers to manage their energy networks, increase uptime and improve reliability, asset utilization, cybersecurity, and energy efficiency to reach sustainability goals.

Electrification X has an integrated user experience, meaning that all data of one station is available to the user in one place with a harmonized data structure and user experience. For example, there is one login to the system, a general map view of all connected stations, a list of all alarms and events, and a common asset topology with all connected assets.

Electrification X has six feature sets that have dedicated use cases and value propositions: Load Management, Network Fault Management, Asset Management, Sustainability/Energy Management, Distribution Grid Monitoring, and OT Companion.

With different feature sets, Electrification X helps our customers to:

- Manage rapidly growing EV charging networks while keeping the grid stable
- Localize and manage network faults efficiently
- Increase uptime and improve asset utilization while reducing OPEX
- Reduce energy cost and CO₂ emission
- Keep the distribution grid stable
- Ensure cybersecurity



|| Digitalization is mandatory for a successful energy transformation. Digital Twin technology, however, is essential to make the energy transformation affordable and keeping grids reliable and the energy supply sustainable and safe.

Stephan May, CEO of Electrification & Automation business at Siemens AG

A look into the future of Digital Twin supported Asset Management

New service models in the making

The white paper concludes with a look to the future which is already in the making, with Siemens Xcelerator, Electrification X Asset Management and Electrification X Asset Management Twin. So let us imagine the year 2034 from a manager's perspective, responsible for an industrial or public power grid:

As the world is slightly behind the most ambitious CO₂ reduction targets [8], the pressure to decarbonize and electrify the entire value chain remains high. This means that assets are operating under new and more variable conditions. In such an environment, old rules of thumb are no longer reliable, especially as a lot of experienced personnel are retiring.

Being aware of tomorrow's challenges, the company made together with Siemens the decision to implement an integrated IoT suite. While it was understood that such an IoT suite wouldn't solve all problems immediately, its focus on the Digital Twin, APIs, and adaptability to multiple and evolving use cases was convincing. Initially, the focus was set on critical assets, using a conventional approach that involved installing additional sensors and meters. However, smart concepts allowed for a seamless implementation without any unnecessary shutdowns.

Over time, this concept was extended to all our electrical assets, the number of sensors adjusted accordingly to the project's need. In some cases, no additional sensors were needed, thanks to the use of existing data sources. The holistic approach of this suite, focusing on the entire grid, enabled



us to onboard all our assets, independent of the original manufacturer. We now benefit from the advantages of an ecosystem such as Siemens Xcelerator, fostering collaboration between all stakeholders: operators, multiple OEMs, service providers, just to name a few.

The increased transparency did not only help to prevent failures, but also optimized maintenance scheduling and identified weak spots in our power grid, strengthening the system's resilience. As a result, most assets are now covered by performance-based contracts that include aspects like spare part availability, cyber-security, and asset availability itself. Not only have our key financial figures considerably improved, also our sustainability commitments are on track, with both scope 1 and 2 emissions on a net zero pathway. While the journey to this new sustainable world has been challenging, the team has successfully been supported by this tool suite and the newest team member cannot imagine working without.

References

- [1] For further reading on the electrification of everything, Siemens (2022), Accelerating the electrification of everything, <https://www.siemens.com/global/en/company/about/businesses/smart-infrastructure/downloads-events/accelerating-the-electrification.html>
- [2] This is based on the NZE solar scenario presented in the World Energy Outlook 2023, page 38: IEA (2023), World Energy Outlook 2022, IEA, Paris <https://www.iea.org/reports/world-energy-outlook-2023>, License: CC BY 4.0 (report)
- [3] IEA (2024), Electricity 2024, Analysis and forecast to 2026
- [4] See M. W. Grieves and his presentation at the University of Michigan in 2002 as explained by himself in M. W. Grieves (2016), "Origins of the Digital Twin Concept"
- [5] See Siemens (2020), Simulation & Digital Twin, A 10-Year Technology Outlook. Siemens also offers for years multiple products focusing on a Digital Twin, an example for a protection device is SIPROTEC DigitalTwin, <https://www.siprotec-digitaltwin.siemens.com>
- [6] For further information on the single source of truth, we refer to VDE Association for Electrical, Electronic & Information Technologies: The Digital Twin in the Network and Electricity Industry, VDE Study, Offenbach am Main, Germany, May 2023
- [7] Virtual sensors, also called soft sensors, are not a piece of hardware, only realized in software. They require an underlying model, for further details see Siemens (2019), Model-based system testing: Efficiently combining test and simulation for model-based development
- [8] There is still a large gap between current ambitions and the 1.5 °C goal, according to the International Energy Agency's flagship report, the World Energy Outlook 2022. Under the stated policies scenario, the share of fossil fuels would still account for 60 percent or 32 gigatons of energy-related CO₂ emissions by 2050. The additional national pledges scenario – if implemented – would only lower these emissions to 12 gigatons by 2050. IEA (2022): Executive Summary, in: World Energy Outlook 2022. <https://www.iea.org/reports/world-energy-outlook-2022/executive-summary>

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We create technology to transform the everyday, for everyone. Our world is changing at an unprecedented rate. Demographic change, urbanization, glocalization, environmental change, resource efficiency, and digitalization are presenting new challenges and opportunities.

Siemens Smart Infrastructure addresses these topics by combining the real and the digital worlds.

Our technology transforms infrastructure, across buildings, electrification, and grids, at speed and scale, enabling collaborative ecosystems to accelerate our customers' digital journey to become more competitive, more resilient, and more sustainable.

[siemens.com/smart-infrastructure](https://www.siemens.com/smart-infrastructure)

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