WHITE PAPER

The Reinvention of Transmission Line Design

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Advances in artificial intelligence, machine learning and digital twins are transforming the manufacturing and automotive industries. They could also dramatically improve transmission line design. By integrating historical data with emerging computer science and information technologies, utilities can bring stability and reliability to an electric grid that has grown increasingly unpredictable.

For many utilities, meeting the increased demand for electricity over the next decade and beyond will not be easy. In fact, a recent report from GE calls it the world's most significant challenge between now and 2030.

There are many reasons why. Demand placed on the electric grid is increasingly unpredictable. The increased use of distributed energy resources and battery storage, coupled with surging demand for electric vehicles, increases the difficulty of forecasting load accurately. Heat waves, pandemics and other unprecedented events further increase supply and demand volatility.

Emerging technologies in computer science and information technology, including artificial intelligence (AI), machine learning and digital twins, may offer some of the answers the power industry needs as it builds out transmission infrastructure.

By identifying the combination of variables that can lead to failures, these tools can help improve the stability and reliability of transmission lines and their assets. All have the potential to help utilities solve common, recurring problems while also preparing for unpredictable events.

The Case for AI

AI makes it possible to analyze enormous amounts of historical data and use it to solve problems. Machine learning, a subset of AI, allows a machine to learn by itself from past data to improve performance. Both can come in handy when designing transmission lines, transmission structures and substations.

Consider that utilities tend to standardize the design of these assets with little variation in codes and standards from year to year. Even so, design is typically the longest phase in these projects. Using AI software, utilities can streamline this process by using historical design information on span lengths, and on weather and loading conditions, to predict future designs for similar weather and load conditions.

AI does not replace the engineer or reduce the design team's responsibilities. Because AI programs can be configured to predict outcomes, they can function as a design aid, enabling the engineer to use design time efficiently and expedite the design process. AI's application is not limited to structure design; it can also be used to predict a project's line loading information, conductor selection and bill of materials.

The Case for Digital Twins

A digital twin is a virtual representation of an object or system that spans its life cycle and is updated using real-time field data. Since its development more than two decades ago, digital twin technology has supported the manufacturing, aerospace, automotive and power generation industries. It also has applications in transmission line design.

For example, standard practice calls for a line simulation under various weather conditions during transmission line design and analysis. Engineers use the results of these simulations to study structure and conductor behavior. Throughout a line's service life, utilities conduct regular inspections and maintenance activities to identify safety concerns or structural issues.

Creating a digital twin goes beyond this standard simulation. Rather than waiting for an inspection to identify dangerous conditions, a digital twin monitors and communicates structure condition, conductor clearances and other critical information in real time. Advance knowledge of impending failures enables utilities to prepare for and prevent them, which can be especially valuable during storms and other extreme weather events.

When coupled with AI algorithms and historical data, a digital twin is capable of scheduling predictive maintenance activities as well. Because lines are monitored in real time, utilities can more easily budget and allocate funds for the most critical projects.

Utilities can choose from four different types of digital twins: component twins, asset twins, system twins and process twins. Each has a different purpose. How digital twins are applied in a transmission line application depends on a utility's end goals.

For example, a utility that wants a twin created for a single dead-end clamp or a single davit arm would choose a component twin. If it wished to replicate how a conductor and insulator interact, the utility would develop an asset twin. System twins and process twins — the optimal digital twins for transmission line applications — enable utilities to study their entire transmission system. By revealing how the complete system works together, these digital twins help utilities understand overall efficiency and effectiveness.

Bentley Systems, OpenAI, JetBrains, Tabnine and IBM are among the technology companies developing AI and digital twin technologies using AI, Internet of Things (IoT) and data analytics. These systems consist of an open, connected data environment (CDE) that runs digital workflows. They can execute user-established criteria, run scenarios and predict outcomes related to the performance and maintenance of physical assets.

Additional Utility Applications

Transmission line and substation assets are not the only utility applications to benefit from these tools. Utilities can use AI and machine learning to predict fluctuations in the flow of energy onto the grid. Given the growth in EV charging, battery storage and home renewable energy production, all of which contribute to this fluctuation, this information is vital.

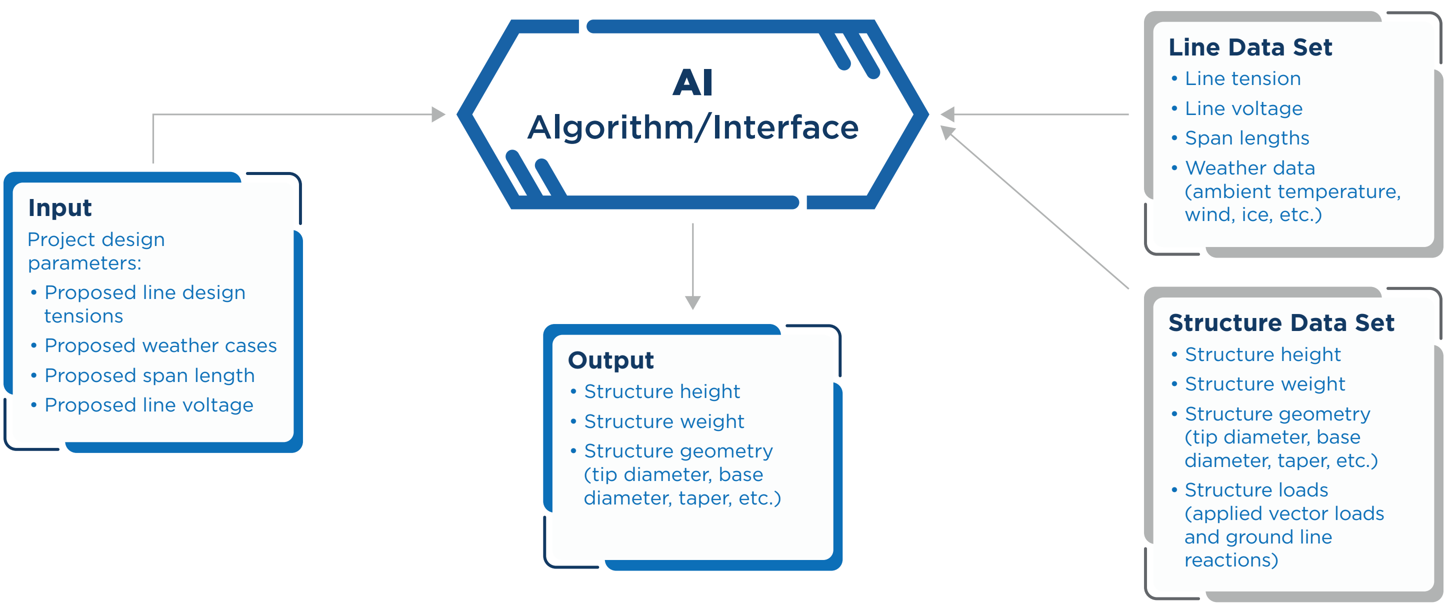

***Figure 1:** AI implementation process flowchart in transmission line design.*

AI and machine learning can also support transmission planning and real-time grid demand optimization by allowing utilities to study and predict grid needs. When used in machine learning algorithms like support vector machines, historical data can also help forecast energy usage and eliminate supply gaps.

By differentiating an actual on-site failure from a cyberattack that mimics failure, AI and machine learning tools can harden transmission systems' resilience to cyberattack. Symbolic dynamic filtering, an information theory–based pattern recognition tool, can detect malicious code or bots as well.

Modeling Framework for AI

The validity and accuracy of AI-predicted solutions depend entirely on the merits of their data sets. At a high level, the AI framework process begins with the development of a user interface that outputs design information based on user input data.

Two data sets are built into this framework. The first, a structure data set, contains historical structure design information, such as structure height, geometry and loads. The other, a line data set, contains information related to line loading, line tensions, line voltage, span lengths and weather. To improve data quality, and thus the accuracy of predicted solutions, these data sets should be updated regularly with project data as new construction is completed.

Span length, design tensions, voltage, line information and other design parameters are entered into the AI interface when new projects are in design. The interface then interacts with the data sets, searching for the closest match to a past structure design. The process flowchart (Figure 1) illustrates AI integration in overhead transmission line design.

Modeling Framework for Digital Twins

Digital twins can be introduced either during or after construction. The process begins with designers creating a visual model of the existing structure or line in the digital twin interface using design drawings or products like PLS-CADD, PLS-Pole and Tower software. The deliverable is a five-dimensional building information model (BIM) using 3D geometry, IoT time-based measurements/performance, maintenance records and costs.

Using a cloud-based platform, designers next develop an interface for the transmission line digital twin. That includes defining criteria and acceptable limits for the items to be monitored. Such criteria might include structure tip deflection, bottom conductor sag and conductor temperature.

Sensors installed on field assets extract operational data and communicate it to the interface. Advanced analytics and machine learning embedded in the interface then identify patterns, comparing current data with the acceptable limits to provide early warnings of impending failures in existing structures or lines (Figure 2).

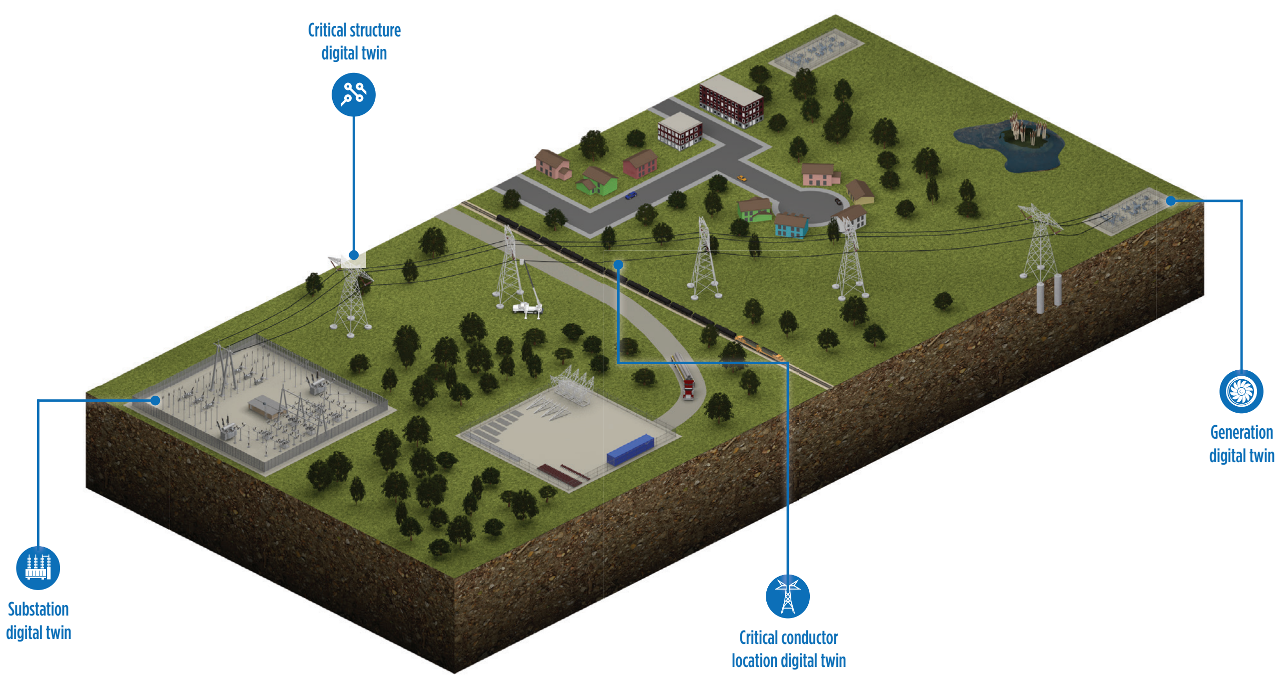

***Figure 2:** Potential locations of digital twins in a transmission system.*

Benefits of AI, Machine Learning and Digital Twins

Transmission line designs that incorporate AI, machine learning and digital twins offer a variety of benefits:

- **Asset quality** — AI-predicted designs can serve as benchmarks and decision-support tools during the quality assurance and quality control review process.
- **Continuous improvement** — With AI, standardized structure designs can evolve over time as new data becomes available. Digital twins, meanwhile, make it easier to monitor and understand life cycle engineering of transmission line assets, which can also inform any changes and improvements designers make to existing design specifications.
- **Asset management** — Digital twins dramatically improve a utility's ability to monitor the structural health of existing transmission line and substation assets. Real-time assessments of structural conditions make it easier to locate areas of concern, especially during extreme weather events. Following a storm, for example, engineers can assess line condition by monitoring structure integrity, conductor condition and the presence of any compromised clearances.
- **Cost management and savings** — As project costs are estimated more accurately, utilities can better manage budget allocations. Further, their ability to support preventive and predictive asset maintenance increases system reliability while optimizing operational and maintenance costs.
- **Safety and security** — By recording injury-related incidents through the interface, utilities can identify trends and implement responses that improve worker safety. Tower-mounted, AI-powered robotics can also help utilities meet North American Electric Reliability Corp. (NERC) standards on physical security.

The Challenges Ahead

The utility sector lags the manufacturing and automotive industries in the use of AI and digital twin technology. Perhaps the most comparable application to transmission lines to date is the digital twins already created for wind turbines.

Utilities aiming to speed up the adoption and implementation of AI and digital twins for transmission lines face several challenges:

- **Workforce adoption** — The success of any new tool or technology depends largely on the workforce charged with implementing it. A 2020 EPRI report suggests that these technologies will require two kinds of professionals: virtualizers who create digital twin content in 3D and virtualists who are comfortable working with the digital models. The EPRI study also recommends creating dedicated branches within engineering for these two roles and enlisting a chief digital officer for strategic guidance.
- **Process changes** — Integrating these technologies into project workflows will require new digital interfaces and process adjustments. For example, to improve AI algorithm accuracy, completed projects should be entered in the database during closeout. Digital twins will require cloud-based databases to store field data.
- **Cybersecurity concerns** — To protect data, asset information stored in the cloud will need to be properly secured, with necessary measures taken to mitigate the risk of cyberattack.
- **Economics** — Until a utility establishes a standardized platform for these technologies, the cost of developing and maintaining them will be high. Once a framework is in place for a single transmission line, however, a utility can apply it more easily and economically to its other lines.

Next Steps

Information technology and accelerated computing have taken giant leaps forward in recent years. The New York Power Authority, among others, has undertaken pilot projects to study how machine learning and AI algorithms can aid the utility's understanding of electricity flow and ability to detect faults. But that work is just the tip of the iceberg. Based on experience in other industries, these powerful tools have the potential to transform transmission assets' design, post-construction monitoring and maintenance operations.

For AI, machine learning, digital twins and other emerging technologies to be adopted in mainstream transmission line planning and design, however, more research and pilot projects are needed. The time to begin this important work is now.

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