From Generation to Supply: Transmission and Distribution (Part 2)

The demand for renewable energy has never been this high. But how can so much generation capacity be connected to the grid?

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From Generation to Supply: How AI is Transforming the Energy System" is a six-part series on the many ways in which AI is helping to transform the energy sector at every stage of the generation, transmission and distribution, system operation, supply, and regulation cycle. This is Part 2. The next part will appear in April, 2023.

It is 2030. A growing number of organizations continue to pledge more ambitious targets for Net Zero. The demand for renewable energy to power factories, cities, and many other operations has never been this high. But this transition has one challenge – how can such a high degree of generation capacity be connected to the grid?

The reality is that we don't need to look to the future. The constrained grid availability is already a problem today! Across many countries, Transmission Network Operators

(TNOs) and Distribution Network Operators (DNOs) are struggling to connect new renewable generation as fast as demand grows.

TNOs and DNOs expanded the grid for years by way of centralized utility-scale power plants, a single directional flow of electricity, and low visibility of individual asset consuming power. Add to this equation the aging infrastructure, the decentralized profile of new power plants, and the exponential growth of electric equipment like electric vehicles (EVs) and heat pumps. The result is a myriad of complex challenges facing grid operators to enable energy system decarbonisation.

But the pressure to become more efficient in expanding grid capacity without relying only on new hardware construction has triggered a transformation in the operating models of TNOs and DNOs. Many of these companies are looking to become Transmission and Distribution System Operators (TSOs & DSOs), building services and innovative techniques to operate their infrastructure, harnessing the power of their data, and optimizing both current and future asset development.

Transmission & Distribution: What Are They?

Electricity Transmission and Distribution companies are responsible for the physical movement of electricity from generators to the end-users. These companies operate and maintain the infrastructure that transports electricity over long distances and through local neighborhoods. But although both are directly connected to the electricity grid, TSOs & DSOs have some differences regarding size, operating voltages, and geographical coverage.

The primary difference between TSOs and DSOs is the voltage level of the electricity they handle. TSOs operate high-voltage power lines that transport electricity over long distances, typically from generation plants to substations. On the other hand, DSOs operate lower-voltage power lines that carry electricity from the substations to homes, businesses, and other consumption points like street lights. Another key difference is the size of the service territory. TSOs generally cover a larger geographic area and serve multiple states or regions, while DSOs tend to operate within a single state or smaller region. Despite these differences, both types of companies share the goal of delivering reliable and affordable electricity to consumers.

AI and the Evolving Landscape

Three high-level functions summarize TSOs and DSOs' responsibilities: expanding their grid infrastructure, asset operation and maintenance, and capacity planning and allocation for new electricity assets.

Grid Expansion

Grid infrastructure expansion is probably the most challenging responsibility for TSOs and DSOs under the current pace of renewable energy development. Whether building major electricity substations offshore to connect large wind farms or reinforcing a local transformer capacity to accommodate the expansion of an industrial district in a city, these types of engineering projects require complex long-term planning. Grid operators need to identify the optimal location, negotiate land access, avoid or minimize any disturbance to current operations during the construction period, and guarantee the longevity of capacity reinforcement to optimize their scarce resource allocation. It's worth noting that such high demand for new, decentralized connections in a short period was not part of grid operators' expansion plans 5-10 years ago. The solution is moving towards a more agile and data-driven expansion strategy, whereby building new infrastructure is not the only alternative to guarantee grid access.

Powered by robust AI models, DSOs & TSOs are promoting flexibility auctions for both supply and demand before expanding their constrained physical network. With more precise load forecasting, grid operators can identify flexibility zones and periods ahead of time to offer users the option of either turning electricity generation/demand up or down in exchange for economic incentives. AI models not only generate value for grid operators by enabling these alternative solutions; they also have the capability to optimize transmission line routing, combining planning requirements and commercial conditions for new substations.

In addition to optimisation, computer vision techniques make underground cabling cheaper with the possibility of mapping all terrain conditions utilizing different data image signals. There are multiple possibilities for grid operators to accelerate their transition to system operators and unlock more capacity on their current infrastructure without significant capital investments.

Operation and Maintenance (O&M)

Another primary function of TSOs and DSOs is to operate and maintain the grid infrastructure so that the electricity supply is not interrupted. This involves monitoring the grid in real-time, identifying potential issues, and taking corrective actions to ensure the grid remains secure, stable and reliable. There are many reasons for equipment failure, from normal aging to unexpected natural events such as lightning strikes or wildfires. No matter the reason for an outage, they're unwelcome, especially for critical infrastructure like hospitals.

On the other hand, the multisensors' visibility into transformer level (TSOs) or the meter level (DSOs) data is an ability that grid operators have acquired recently, mainly spurred by technology developments like the Internet of Things (IoT) and the demand for real-time control on an asset level to cope with a more dynamic grid. However, the capacity to see and handle thousands of machines and sensors on the grid requires a lot of investment. Even given these recent developments, operators have room for improvements in how smartly they maintain the network.

One quick win for grid operators would be to improve the accuracy of asset allocation in their systems to lower the risk of outages caused by overstressing transformers' limits. Advanced analytics, in combination with physics models, propose a more efficient way to identify meters that have been wrongly allocated to transformers, *prior* to failures, saving time and engineering resources. For more complex operations, deploying deep learning algorithms enhances grid protection by recognizing defects quicker and avoiding a negative ripple effect on the network, as well as against cyber attacks on the system.

Finally, grid operators are trialing new preventive maintenance techniques combining computer vision and smart devices like drones. Manual and laborious tasks such as photo labeling and asset inspections are giving way to autonomous data collection and processing. There are countless benefits for grid operators in modernizing how they operate and maintain the grid, including more reliable data, lower health and safety risks for their workforce, and major efficiency gains.

New Connections

The third main function of grid operators is offering and managing new connections to their infrastructure — both electricity supply units like solar and wind generation, and demand-side requests like new factories or ultrarapid EV chargers. However, before granting access to the grid, operators undertake a complex process to assess the impact of the new connection within the broader network. This includes analyzing the substation's available capacity, equipment voltage, and thermal constraints; for generation plants, it also involves determining when that unit will produce electricity (e.g. solar plants produce more during summer than winter periods).

On an interconnected grid, this assessment goes from the substation where the grid operator physically connects the asset, and triggers an upstream analysis of higher voltage substations and cables to guarantee the whole grid operation is not at risk. The result is an extensive backlog of applications waiting for engineers to assess whether they can connect or not, and, if they can, what the optimal design format would be, including costs of reinforcement, timeline to provide the service, and type of connection.

Coupling AI with the current human-dependent connection assessment is a win-win situation for TSOs and DSOs. Engineers overloaded with pilling applications can redirect their focus to more impactful tasks like designing new products and more complex multi-technology connections. On the other hand, grid operators can improve their breadth of services while increasing their quality and that of the user experience.

One successful example of speeding up approvals is deploying AI to assess requests for low-impact connections to decentralized energy resources. This is not only more efficient, but also provides an incentive to connect to greener technologies to accelerate system decarbonisation. Moreover, AI value generation goes beyond present applications. Developing smart capacity allocation models includes improving the ability to predict where and when users will require grid capacity.

Whether expanding their assets more efficiently or modernizing how they allocate capacity, grid operators have a long road ahead in their transition from network operators to system operators.

Moving to Everyday AI in Electricity Transmission & Distribution

These three central grid operators' functions have major synergies in their daily operations, yet it is common to see these functions siloed in different teams across companies responsible for electricity grids, leading to a lack of collaboration and underexploited operational synergies across teams, and long development cycles for their models. Engineers with long lists of connection applications are not the only ones bottlenecked. Data science teams inside grid operators suffer from an equivalent challenge: dealing with an extensive backlog of internal requests for solutions, either because business units do not have access to analytics, or because they lack the advanced coding skills to extract insights from the data.

Implementing a platform on which multiple teams can work together on building more complex solutions to long-standing problems like delayed grid connections has the potential to transform TSOs and DSOs operations. Technical teams can have a more hands-on and agile approach to developing solutions when coding is not a mandatory skill to analyze the data available and understand where they could improve their processes. And IT teams do not have to trade off security and governance as to how users access, manage, share and deploy models and data. On the other hand, backlogs filled with simple tasks give way to more automation and complex solutions where data scientists work side-by-side with engineers to leverage their specific knowledge.

An end-to-end platform where coders and low coders co-exist is essential for enabling grid operators to truly embed data into their routine, scale their innovation potential with new services powered by AI/ML models, and optimize constrained human and financial resources to enable the electricity system decarbonisation.

What's Next

The IEA expects grid transmission and distribution investments to reach USD 820 billion in 2030 to keep the world on track to NetZero. This is 3x more than today's figure, and a strong signal of how important the grid is for enabling other technologies in the transformation of the energy system. To promote their own transition, grid operators need to diversify from their business-as-usual physical infrastructure expansion to a modern grid service provision.

As AI evolves and becomes more common in the industry, TSOs and DSOs will significantly improve grid reliability, efficiency, and cost-effectiveness. In the next blog post, we will explore how Energy System Operators use AI to guarantee the performance of the entire energy system, from generation to supply.