WORLD-CHANGING IDEAS FOR “DECARBONIZING THE GRID”

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Energy is the foundation of our economy and is at the forefront of everything we do. The demand for cleaner electric energy grows each year with electrification of data storage, mobility, space conditioning, vertical agriculture, industrial processes and more.

Some electric energy stakeholders want carbon neutral or carbon free sources of renewable generation and ironically refer to this goal as “decarbonizing the grid.” **There is a dichotomy between decarbonizing the sources of electricity generation and the wires and cables that make up the transmission and distribution (T&D) grid that delivers that electricity.** Nonetheless, there is much work to do to allow the integration of new sources of renewable generation and subsequent storage on the T&D grid or “decarbonized grid.”

There are many new and emerging technologies available to T&D industry planners and engineers to achieve these goals to include artificial intelligence, robots, digital twins, 3D printing and construction, conversion to underground systems, plasma drilling, microgrids, net zero energy buildings, hydrogen resources for grid support and sensor technology to support all of the above.

Planners and engineers will cost-effectively employ combinations of these new technologies to maintain and improve the safety, reliability, and resiliency of the 21st century "decarbonized" grid as it delivers carbon neutral or carbon free sources of renewable generation. In addition, lessons learned on these world changing ideas will be applied to the industry as a whole, new smart cities around the world, and perhaps someday soon, permanent habitations undersea and in space.

Undersea? In space? Just look at what the American Society of Civil Engineers is projecting with their Future World Vision at https://www.futureworldvision.org. The ingenious and imaginative "Floating City" and "Off Planet" models provoke thoughts about what engineers design today for the "decarbonized" grid that can be applied far into the future.

ASCE asks…

As sea levels rise, imperiling coastal communities, one form of mitigation will be offshore floating cities. What kinds of innovative, resilient, multi-modal designs will engineers need to design to take on the rising water?

How will engineers create the fundamental elements of a built environment on Mars under such hostile conditions? How will the first settlers form a viable, sustainable community that will last for generations?

Can you imagine that elements or spin-off technologies from robots, digital twins, 3D printing and construction, plasma drilling, massive conversion to underground systems, microgrids, net zero energy buildings, and hydrogen fuel for mobile and stationary generation and storage will occur in your career horizon?

Central to everything is a new age of artificial intelligence built on high quality, data from ubiquitous sensors on everything.

Artificial Intelligence

Artificial Intelligence (AI) is the "new electricity" and data is the fuel, says Kai-Fu Lee in his provocative book *AI Superpowers, China, Silicon Valley and the New World Order.* It is ironic that Lee uses the electricity metaphor for AI. The electric grid was declared the greatest engineering achievement of the 20th Century by the National Academy of Engineering in 2000. Greater than the airplane, plastics, fertilizers, antibiotics, the assembly line and more, and the electric grid changed the world. Now, AI is poised to change the world.

Artificial Intelligence, like the human brain, functions around "pattern recognition." As a child, we learn by using our five senses to communicate to our brain. Over time, our brain recognizes the look, feel, smell, sound or taste of an infinite number of people, places and things. With today's advanced computing technology and massive amounts of data storage, a computer can do the same thing. Artificial intelligence is defined by *Webster's Dictionary* as "a branch of computer science dealing with the simulation of intelligent behavior in computers: the capability of a machine to imitate intelligent human behavior." There are different types of AI, ranging from simple rule-based systems to more complex machine learning algorithms that can learn and adapt over time.

Some general applications of AI include:

1) Image and speech recognition: AI can analyze and interpret images or audio recordings allowing machines to "see" and hear" and understand their surroundings.
2) Natural language processing: AI can process and understand human language allowing machines to communicate with humans in a more natural way.
3) Decision-making: AI can analyze data and make decisions based on that data allowing machines to act autonomously or assist humans in decision-making.
4) Predictive analytics: AI can analyze data and make predictions about future outcomes, such as demand for a product or the likelihood of an equipment failure.

There are several ways in which AI can specifically benefit the T&D industry, including:

1) Predictive maintenance: AI-powered systems can analyze data from sensors on T&D equipment to predict when maintenance or repairs are needed before an outage
2) Fault detection and classification: AI algorithms can analyze data from sensors on T&D equipment to detect and classify faults, such as short circuits, downed conductors or broken insulators. This can help utilities respond more quickly to wildfires and weather-related events to improve system reliability and resiliency.

California wildfires rage out of control and require new, proactive solutions

3) Demand forecasting: AI can be used to analyze data on past electricity consumption patterns, forecast future demand and simulate DER integration allowing utilities to better plan and manage their T&D systems.

4) Energy management: AI can optimize the use of electricity by households and businesses by analyzing customer data on energy use, data from a ubiquitous sensor network on secondary and tertiary sources, and the current or proposed grid configurations to make the decisions for efficient energy usage

Among many other sources of data, AI will be complemented by robots gathering valuable data and working in the field and the office.

Robots

A robot is a machine that duplicates certain human movements and functionality. Robots are made in a human or creature-like form or simply look like a large machine with multiple appendages. Robots generally perform unsafe, hazardous, highly repetitive, and unpleasant tasks. However, they can take the form of scanners and kiosks at your local grocery store, fast food restaurant or airport to replace costly human employees that are hard to recruit, train and retain. While robots are more pervasive in our daily lives, the electric T&D industry is discovering useful applications for robots such as security, inspection and maintenance, construction, and even mail delivery.

The new security robot in the T&D industry is Spot the "robotic dog" by Boston Dynamics. Robots, like Spot, can be used in confined and hazardous spaces to provide eyes and ears to the user for security and inspection. Other forms of robotic inspection can be conducted by drones or unmanned aerial vehicles (UAV's) that reduce the need for manned aircraft inspection and deliver vast amounts of asset condition data to be used for maintenance decisions. Drones can also be used to laser scan entire project sites to accurately map asset location, material quantities, work progress and more. Construction and maintenance can be performed with robotic arms that keep human personnel a safe distance from energized electrical lines. The LineMaster Robotic Arm by Quanta Services is a proprietary live-line tool that allows for the safe capture, control, and movement of energized conductors without the need for temporary provisions. New advancements in robotic for the industry can be expected by other entrepreneurs and the Electric Power Research Institute (EPRI) as the pressure on skilled labor cost and availability grows. Watch for developments in tree trimming and vegetation management, simple substation switching, and safe and rapid installation of millions of sensory devices in hard to access and hazardous locations. The use of robots in electric transmission and distribution systems will increase in the coming years as utilities seek to improve their efficiency, safety, and reliability of their systems and personnel and seek to have a better understanding of their assets via tools like the Digital Twin.

Digital Twins

The digital twin is a multi-dimensional model or representation of a physical asset, infrastructure system or city that provides valuable information about asset location, cost, condition and performance. The digital twins is constantly updated from multiple human, robotic and sensory data sources. They are not a static three (3) dimensional (x, y, z) model and can include dimensions for schedule (4D), cost (5D), ESG scoring (6D) and more. The digital twin of the overhead and underground electric transmission and distribution system is a virtual replica of the physical system. It is a computer-based model that incorporates data from various sources, such as sensors, meters, robots and other monitoring equipment, to provide a detailed and accurate representation of the electric system. The digital twin can simulate various design scenarios such as the integration of distributed resources like renewables, storage, electric vehicles (EV) or fuel cells. The digital twin can assist operators with condition assessment and predictive analyses of asset condition as part of an asset management program or asset health center. This can help utilities optimize their asset management strategies and extend the life of their equipment. Further, the digital twin can simulate asset performance during high impact-low probability (HILP) events such wildfires, ice storms, tornadoes or even cyber-attacks.

The digital twin of the electric transmission and distribution system provides utilities with a powerful tool for optimizing their operations, improving the reliability and resiliency of the grid and lowering the cost of the asset over its useful life. This leverage allows utilities to apply other advanced technologies to benefit their safe, reliable and resilient operation. One such technology is 3D printing and construction.

3D Printing and Construction

3D printing construction has the potential to impact the electric transmission and distribution industry in several ways such as:

3D printing can be used to create durable replacement parts on the jobsite for some T&D equipment and potentially reduce downtime and repair costs. Plastic parts, panels or enclosures in substations or in manholes will be the starting point. As print feedstock metallurgy advances this opportunity will grow significantly and improve the ability to solve some critical path supply chain issues with a printed part rather than a long lead time part from a faraway factory.

The possible schedule impacts of 3D printing will be hard to quantify, but real. If we intend to build out the "decarbonized grid" to match the ambitious 2040-2045 goals for renewable and nuclear decarbonized generation resources, supply chain schedules for key components will be crucial. If we plan to build as much as 50% underground distribution by 2040, 3D printing and construction will have a significant role to play in achieving the goals.

Underground

Today, the electric distribution system in America is approximately 20% underground. It's a long way from 50%. Yet, some public power utilities like Ft. Collins, Colorado Springs, and Anaheim have had underground ordinances for years. They have beautified their cities and improved the performance of their sys- tems. Fort Collins is 99% underground and is 99.9% reliable. Colorado Springs started in the 1970's and today is 77% underground with 99.9% reliability.

Colorado Springs overhead transmission line with underground distribution

Anaheim has been engaged in their Home Underground Program (HUG) since 1990 with excellent results. And, the phone and cable TV utilities in Anaheim paid to go underground as well.

Investor owned utilities (IOU's) have put new neighborhoods underground for years, and now, many large IOU's like PG&E, FP&L,WEC Energy Group and Dominion are engaged in multi-year, multi-billion dollar programs to "strategically" underground laterals and other key parts of their systems.

50% Underground by 2040 is an aggressive goal but achievable when evaluating the total cost of ownership over the life of the asset

These municipal and IOU's are starting to understand the total value of underground over the life of the asset. The data supports it. Data on capital cost, data on reduced operations and maintenance (O&M) cost, time and safety exposure, data on customer satisfaction, data on reliability measured in minutes, and data on resiliency measured by total time of line restoration (TLR).

Technological and material advances now make underground electric distribution more safe, reliable and resilient. And, the benefits of undergrounding have been clearly documented in several industry reports and construction costs are coming down.

These utilities and their regulators and public power boards are leading the way with strategic undergrounding programs. More system and cost data will come from these projects in the coming years. So, yes,"50% underground by 2040" is a dramatic and very progressive goal. But, its a goal that will provide a 21st century "decarbonized" grid of the future to deliver the equally progressive renewable, net zero and carbon free goals of that same future.

Plasma Tunnel Boring

Building dramatically more underground T&D will require more human and material resources, and technological advancements to deliver at scale. One advancement that shows great promise is the plasma boring, drilling and cutting under development by EarthGrid.

EarthGrid is a venture capital, start-up that is developing the world's first way to tunnel, trench, and excavate using our patented plasma tunnel-boring technology. Compared to traditional tunneling, trenching, and excavation methods, this technology has the potential to work exponentially faster and save dramatically in costs.

Plasma boring is a technique that uses a plasma torch to bore, drill and cut holes through rock and soil. The process involves directing a high-powered plasma arc at the rock and soil material, causing it to melt and vaporize into "cornflake" sized chaff leaving a hole or trench which can be used to install conduits or cables for underground electric lines.

Plasma boring is energy intensive and generates much waste heat in the excavation. EarthGrid is working on these challenges and has patented their technology and are proving it at scale. If successful, they will deliver faster underground installation times, reduced utility and environmental disturbance, and increased locational accuracy. Plasma boring, drilling and cutting may be fundamental to the industry's ability to deliver the changes needed to meet the goals stated.

The 21st Century grid will still need to be safe, reliable, resilient and affordable while it is massively overhauled to accommodate electrification and distributed energy resources like local generation, storage and electric vehicle (EV) charging. Building underground is a big part of the new "decarbonized" grid. So too, are redefined microgrids.

Microgrids

Microgrids are stand alone clusters of electric customers served by onsite generation that can seamlessly connect and disconnect from the legacy grid. It will provide critical electric service to strategic areas throughout a community during times of high impact, low probability (HILP) events with little or no customer outages.

Microgrids are an excellent solution for much needed resiliency but are expensive and very difficult to permit when using carbon based stored fuels. As a result, we do not build many microgrids. Therefore, the industry needs to redefine a microgrid.

A microgrid should be redefined and "reimagined" without onsite carbon fueled generators and with the development of resilient electric infrastructure such as a dedicated, hardened overhead or underground feeder(s) or transmission line.

Imagine a select portion of the grid remaining in service after a wide area catastrophic event. The surviving partial system would provide service to multiple small portions of communities across a large metro area. Homes may be out of power, but potable water would still be available. The toilets could be flushed and sanitary systems could still operate. Mobile phones could still operate and customers would still have access to news and emergency information. Phone charging stations could be available and a limited number of grocery stores and gas stations could still operate. Community centers could be available for heating or cooling in extreme weather as well as providing food, water, and shelter.

Critical infrastructure can be protected with a "redefined" microgrid

Reimagined microgrids will survive HILP catastrophic events, remain operational, and provide electric service to multiple small areas (microgrids) of communities across large service territories. In time, clean, carbon-free hydrogen resources may be applied to microgrids.

Hydrogen

Hydrogen is produced from methane or water using energy intensive processes to separate the chemical elements. Hydrogen is an exciting area of development for the energy industry and has the potential to transform the delivery and use electricity. It can support electric system operations and microgrids in several ways:

Hydrogen can be used as a form of energy storage for electric systems. Excess renewable energy, such as from wind or solar, can be used to produce hydrogen through electrolysis. The hydrogen can then be stored and used to generate electricity during times when renewable energy production is low.

Hydrogen fuel cells can be used to generate electricity, providing a clean and efficient alternative to traditional combustion-based power generation. In addition, fuel cells can be used to power electric vehicles, homes, microgrids and even entire communities.

Hydrogen can be used to balance the electric grid by providing a flexible source of power that can respond quickly to changes in demand or supply. Hydrogen fuel cells can be used to provide backup power during times of peak demand, reducing the need for fossil fuel-based peaker plants. And, Hydrogen can be used to power remote sensors and monitoring equipment on the T&D system. Finally, Hydrogen fuel cells can be part of a portfolio of generation, storage and demand side management tools used to successfully operate and maintain net zero energy buildings.

Net Zero Energy Buildings

Commercial buildings consume 40% of energy and emit 40% of all carbon dioxide in America. Net zero buildings can help us start to achieve our environmental goals and provide unique and valuable new business opportunities at the same time.

Net zero can be defined several ways. The best definition for early applications is “the net energy or water used for an asset over the course of a one year period is produced on site.” Buildings, facilities and plants experience peak periods of energy and water use as temperature, humidity, consumer use and production levels vary. During these peak periods, the facility will need to be connected to the electric, gas or water distribution systems of the local utility.

The zero carbon ECO District by Avista in Spokane
is leading the way in net zero design.

One progressive idea is to design and build a Direct Current(DC), Net Zero Energy (annualized) microgrid at a greenfield industrial site powered by 1)onsite wind and solar plus storage, 2) onsite natural gas converted to hydrogen with renewables for microgrid system support, AND 3) a highly resilient, dedicated underground HVDC and back-up AC transmission line built connected to an existing regional transmission system.

The microgrid will use demand side management (DSM) and demand response (DR) to control the specially designed DC loads and some AC loads in the state of the art plant, facilities and supporting infrastructure. The customer will be able to arbitrage the plant electrical needs with the regional price of power and need for ancillary services buying and selling both when most profitable. Challenging? Yes, but any way you define it, Net Zero Energy, is hard to deliver especially year over year.

However, the world changing technologies featured herein will synergistically work to make net zero more achievable. In order to achieve this, the T&D industry will need to gather more data on just about everything. Utilities and their customers will need to deploy sensing technology to help plan, design, construct, operate and maintain the “decarbonized” grid of the future.

Data Sensors

Ubiquitous data sensors can be used on the T&D grid and on customer premises in several ways to maintain and improve the safety, reliability, and resiliency of the decarbonized grid.

Data sensors can be used to monitor the electric transmission and distribution system in real-time, providing utilities with instant data that can be turned into information on the condition and performance of their infrastructure. This can help utilities predict and identify potential issues or problems before they become serious and take proactive measures to maintain the system's health and reliability.

Data sensors can be used to discover wildfires, downed conductors, failing cables, voltage anomalies and faults in the T&D system. This can help utilities respond more quickly to these issues and restore power more efficiently. Data sensors can be used during wildfires, extreme weather events or other emergencies like car hit poles, plane impacts, etc to plan for and respond to these hazardous events more effectively in the future. Finally, data sensors as part of a utility provided or proprietary building management system can lead to better and more efficient use of energy and water resources for customers.

Overall, ubiquitous data sensors can provide utilities with the raw data that is turned into valuable information they will use to optimize the performance of the decarbonized grid and maintain a safe, reliable, and resilient electric system. By leveraging the power of data, utilities can improve their operations and support a grid that continues to meet the needs of consumers and communities.

Conclusion

Planners and engineers will cost-effectively employ combinations of these new technologies to maintain and improve the safety, reliability, and resiliency of the 21st century "decarbonized" grid as it delivers carbon neutral or carbon free sources of renewable generation.

The industry and electricity customer will collect massive amounts of raw data on the performance of these new technologies on the grid. New algorithms developed for AI will instantaneously convert data into information and action.

The lessons learned on these world changing ideas will be applied to the industry as a whole, new smart cities around the world, and perhaps someday soon, permanent habitations undersea and in space, on the Moon and, eventually, Mars.

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