THE DIGITALIZATION OF POWER:

A Vision for the Future

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Predicting the future is easy.

Before there were nuclear submarines, there was the Nautilus from *Twenty-Thousand Leagues Under the Sea.* Before the Apollo Program, there was the lunar landing pod, launched from Florida, that carried the astronauts in Jules Verne's *From Earth to the Moon.* In the 1920s, near the dawn of electrification, Nikola Tesla predicted that we would all one day have pocket-sized devices that we would use to communicate via a global wireless network.

Building the future, on the other hand, is difficult.

We know that the digitalization of energy is the only path forward. Given enough time and even a moderate pace of technological development, we know that all the benefits of a digitalized energy infrastructure will come to pass.

GE is committed to building that future as quickly as possible in order to best prepare our customers and the billions of people who depend on them to take full advantage of it. This means devising agile, dependable solutions that stretch the limits of what the current power grid was designed for. It also means imagining what a digitalized power system built from the ground up might look like and then working tirelessly to build it.

What do we think the future has in store?

We imagine a world where power plants, transmission and distribution (T&D) equipment, and end-user energy devices work in seamless harmony to deliver reliable, affordable, sustainable energy when and where it is needed. We imagine a world where key parts of the energy system operate autonomously, providing economic and environmental benefits to homes, business, and factories. We envision a world where substations at the edge of the grid are capable of optimizing transmission and generation second-by-second, and where individual homes can do the same, all with little or no human intervention required. That's the future we see.

To realize this future, we are devising a range of new digital technologies that can be successfully integrated with both existing and new energy infrastructure. As our customers know, the grid is being asked to do things it was never designed for. Utilities are being asked to mix and manage energy sources at a level that they never have before; and actions are being taken at all levels of society – from the increase of home solar to the electrification of cities and transportation to enhanced security – that are adding to our industry's growing list of critical focus areas.

In other words, we live and do business in a mixed energy environment and will be doing so for a very, very long time.

That's why GE continues to leverage our deep domain expertise to design innovative digital solutions that meet the challenges of the future energy grid. We continue to make sure that our platforms are rock solid and offer customers a full set of options for cloud, edge, and on-site deployments.

GE's strong tradition of innovation, along with our enthusiasm for collective endeavors, helps transform markets and revolutionize the global energy landscape.

The world will never be the same.

The Benefits of Digitalization

The foundation that GE and our customers and partners will use to build the power infrastructure of the future is the Industrial Internet of Things (IIoT). At its core, the IIoT is a system that integrates digital information with physical infrastructure via a network of sensors, which detect and relay information, and actuators, which move machines to act on that information. The IIoT generates vast quantities of information that we have never had access to before, and machine learning allows us to turn that data into actionable insights.

In the power sector, IIoT applications and machine learning have been developed to operate and control T&D networks, improve the performance of individual and fleets of power plants, and optimize hybrid microgrid systems. This marriage of the physical and the digital across all industries is revolutionizing how machines work and providing cost and resource savings.

Benefits of the IIoT are already being felt, but even greater untapped benefits will be a game-changer for civilization.

The Global e-Sustainability Initiative (GESI) recently found that an IIoT-enabled world of 2030 can be drastically cleaner, smarter, and more prosperous than the present. GESI's findings indicate that Information and Communications Technologies (ICT) can bring about a 20 percent reduction in global carbon dioxide emissions by 2030. This would also reduce energy costs by US$4.9 trillion, with US$1.2 trillion in reduced electricity expenditures, and US$1.1 trillion in reduced fuel expenses, all by 2030.[1]

The potential impact of a digitalized grid alone is similarly vast. Recent GE analysis suggests that if digital grid technologies were fully deployed globally, electricity consumption could be reduced by as much as 12 percent and carbon dioxide emissions could be reduced by up to 2 billion metric tons by 2030.[2]

12% reduction

in global CO_2 emissions possible by 2030 through broader implementation of digital technologies

That's why we have an imperative to lay the groundwork for a fully digitalized global power infrastructure, starting now.

What it will take to build a digitalized energy infrastructure

If we adopt digital technologies swiftly and comprehensively, the global power infrastructure could be as different a decade from now as ours is from the power systems of 125 years ago.

The adoption of digital technology is already well under way. According to the International Energy Agency's 2017 Digitization & Energy report,[3] digital adoption rates have increased 20% annually since 2014. That's a good start, but to fully realize the benefits of digitalization, we'll need to increase that rate substantially.

And simply adopting digital technology isn't enough. We also need the knowledge, access, and scale to make the best use of it.

[1] GESI, 2015 (from The Digitalization of Energy)

[2] The Digital Grid and the Environment, GE, 2017

[3] International Energy Agency, "Digitalization & Energy" (IEA: 2017), https://www.iea.org/publications/freepublications/publication/DigitalizationandEnergy3.pdf, accessed Sep 8, 2018.

First-hand domain knowledge. From an informational perspective, providing power is a complicated business. It is essential to have the human expertise that can separate the signal from the noise, to know which information is worth acting on. If the global power system were a patient, those with domain expertise are the doctors. Just as, without physicians, even the most advanced medical equipment in the world could not result in better outcomes for patients, so too the most advanced power infrastructure needs expertise to realize its potential.

Access to operational systems is equally critical. The software and controls that drive generation, transmission, and distribution are the backbone of the energy network, and being plugged into them is another key factor that translates insights into action. Having access is the difference between knowing the state of the system and being able to "close the loop," i.e., do something about that knowledge. Partnering with an organization like GE, which touches 40% of the world's electrons on their journey from the point of generation to the point of consumption, is one way to do this. The New York State Power Authority (NYPA), for example, opened a digital mission control center in 2017, which not only allows them to process the gigabytes of data that flow in daily from New York's grid, but to take action through the central facility's ability to control all 16 of New York's power plants, as well as power for New York's airports and subways.

Scalable platforms. As anybody who has followed the larger narrative of digital innovation knows, it is not enough to have the right working solutions. You also have to be able to scale them to the size of new markets. Cloud computing offers the most robust solution to the scalability challenge for energy solutions, but for regulatory, operational, and cybersecurity reasons, many of our digital customers currently have solutions that sit inside private networks, isolated from the Internet.

That said, we have no doubt that in the fullness of time, more solutions will come to leverage public cloud infrastructure. Cloud providers are clearly aware of this trend and are increasingly building tool kits, PaaS (Platform as a Service) components, and SaaS (Software as a Service) components to address these needs. We look forward to a time when the global power infrastructure can leverage public cloud technologies as a backbone even for solutions that require 100 percent uptime.

The path forward is clear, and we know which new tools to bring with us as we travel it. But there are a number of factors that we need to overcome along the way. Aging infrastructure is a major obstacle. Even in the United States, which once had one of the strongest electrical grids in the world, we're beginning to see more blackouts caused by increased stress on the system. This stress is caused by extreme weather as well as the difficulties of managing the increasingly complex dynamics of a decentralizing power system. For those who wish to overcome these challenges, having access to first-hand domain knowledge, operational systems, and scalable platforms is vital.

Better outcomes

Given that changes in the power infrastructure are being driven by a combination of new technologies, it is no longer enough to measure the increased performance of a single piece of technology and call it progress. Progress is now best measured as the production of better outcomes. We believe the following seven outcomes are new benchmarks of progress.

01 | Network-level optimization

Digitalization allows for a new class of problems to be solved, of a higher order than those which previously occupied the attention of the stewards of the global power system.

To understand the potential of optimization at the network level, imagine a single tool, integrated with all digital assets, that is capable of taking into account the current price of fuel, the price of energy on the open market, and second-by-second weather predictions for wind and cloud cover, and which then offers actionable insights whose effects will be felt all the way out to the edge of the network. The days of spreadsheets and day-ahead planning are gone, and the age of real-time, semi-autonomous optimization has arrived—thanks to the combined effects of digital technologies.

02 | Increased asset performance

By attaching sensors to existing assets and by building them into the production of new ones, it is now possible to drastically increase fleet performance.

For example, a large electric utility deployed GE's digital asset performance management (APM) solution across their 1 gigawatt (GW) wind power fleet, covering multiple regions with turbines from six original equipment manufacturers (OEMs). Historically, the utility's inventory and maintenance strategies resulted in an average wind turbine downtime of 30 to 40 days, significantly impacting fleet production and revenue. GE's digital solution improved wind turbine availability and reduced unplanned downtime and maintenance costs. The utility realized a savings of more than US $3 million, directly attributable to the deployment of the APM solution.

03 | A smarter grid

Digital tools are transforming transmission and distribution, better ensuring a match between supply and demand, in the safest, most reliable, and cost-effective manner.

GE's recent digital T&D innovations comprise intelligent substations, regional automation systems, and advanced network operations centers. Realizing that true transformation will require coordinating intelligent actions throughout the digital fabric of infrastructure, GE has developed a comprehensive digital grid architecture.

Case study: IIoT sensors in Cambodia

Cambodian Energy II Co. Ltd. has contracted with GE's Steam Power business and Toshiba Plant Systems and Services Corp. to supply a new 135-megawatt coal-fired power station in Preah Sihanouk, a municipal district in the south of the country. New plants like Preah Sihanouk's will help extend economic opportunity to rural areas, where 85% of the population lives, and decrease the likelihood that Cambodians will leave to find jobs in neighboring countries with more developed infrastructure. The negative effects of increased coal consumption are mitigated by the installation of pollution control technologies and IIoT-integrated software that optimizes operation. One example: weather forecasts combined with data from GE sensors allow for better integration of renewables. If rain is predicted, operators are tipped off to rely more on hydroelectric power. GE sensors installed throughout the nation's existing grid gives the Cambodian government access to data about usage patterns – information that is crucial to building an intelligent, adaptive energy system for the burgeoning economy.

Case study: Wide Area Monitoring System in India

In 2018, the Power Grid Corporation of India, a state-owned grid operator that transmits electricity to half the country, began installing GE Power's WAMS, or wide-area monitoring system. By feeding them data about power fluctuations in real time, a first for India, WAMS will help grid operators detect and prevent events like "Blackout Tuesday," a 2012 outage stranded half the nation's 1.3 billion people without power and left them at the mercy of high midsummer temperatures. WAMS's AI-assisted predictive capabilities reduce the grid's vulnerability to cascading outages. Developed by a global team of GE engineers, WAMS expanded to serve half the country's grid – serving 34 control centers and 340 substations to date. Providing stable power is crucial for the world's fourth-largest growing economy, which is expected to double its power consumption by 2040.

A great example of this coordination is Exelon, a U.S. energy company that has adopted GE's digital platform solutions to help the operation of its entire fleet, including wind, solar, hydroelectric, and natural gas power. Their implementation of machine learning-based analytics has already increased the efficiency and reliability of the electrical grid for Exelon's 10 million customers.

04 | A more intelligent edge

Thanks to the overlay of machine learning on top of the massive amounts of real-time data now flowing in from entire systems, the infrastructure at the edge of the grid is gaining new capabilities. Among other benefits, these capabilities will allow substations or groups of substations to have self-healing and self-provisioning capabilities, and because of their increased autonomy, the entire grid will be less susceptible to the effects of cyber-attacks on central authorities. The rise of plants and substations that can act as individual utilities is well-timed to meet the challenges stemming from the power system's increasing decentralization.

05 | Digitalizing energy consumption

is providing residential, industrial, and commercial electricity consumers with opportunities to more effectively customize their energy use and even manage the production and consumption of electricity.

To empower consumers to control their own demand response, new protocols are currently being developed that connect appliances and other end-use energy equipment to the IIoT in order to enable automation and control. Increased access to information and opportunities for self-determination provided by IIoT-enabled technology will, in effect, turn many energy consumers into "prosumers," customers who not only have a deeper appreciation for the product that they use but who also get a say in its deployment and evolution.

For example, sensor-based lighting, smart controls, and a wide variety of new software technologies are helping commercial buildings, retail stores, and industrial facilities transform themselves into "intelligent environments." These new kinds of IIoT applications are providing an opportunity to deploy more energy efficient technology within the context of a larger digital productivity ecosystem.

GE expects the majority of the 5.6 million commercial buildings in the United States to be retrofitted with more efficient lighting and controls in the next decade alone.

06 | Unlocking new sources of revenue

GE's analytic tools not only reduce operations and maintenance (O&M) costs but also increase revenue by enabling existing plants to run at higher efficiencies across a wider load range, start faster and more reliably, and respond more quickly to changes in demand driven by the greater presence of renewable energy sources on the grid.

07 | Accelerated decarbonization

The optimization that comes from end-to-end digitalization also reduces carbon emissions.

Consider GE's Digital Power Plant (DPP), a suite of digital applications that improve the performance of power plants and reduce asset downtime using cloud-based analytics on GE's digital platform. If DPP solutions were to be installed across

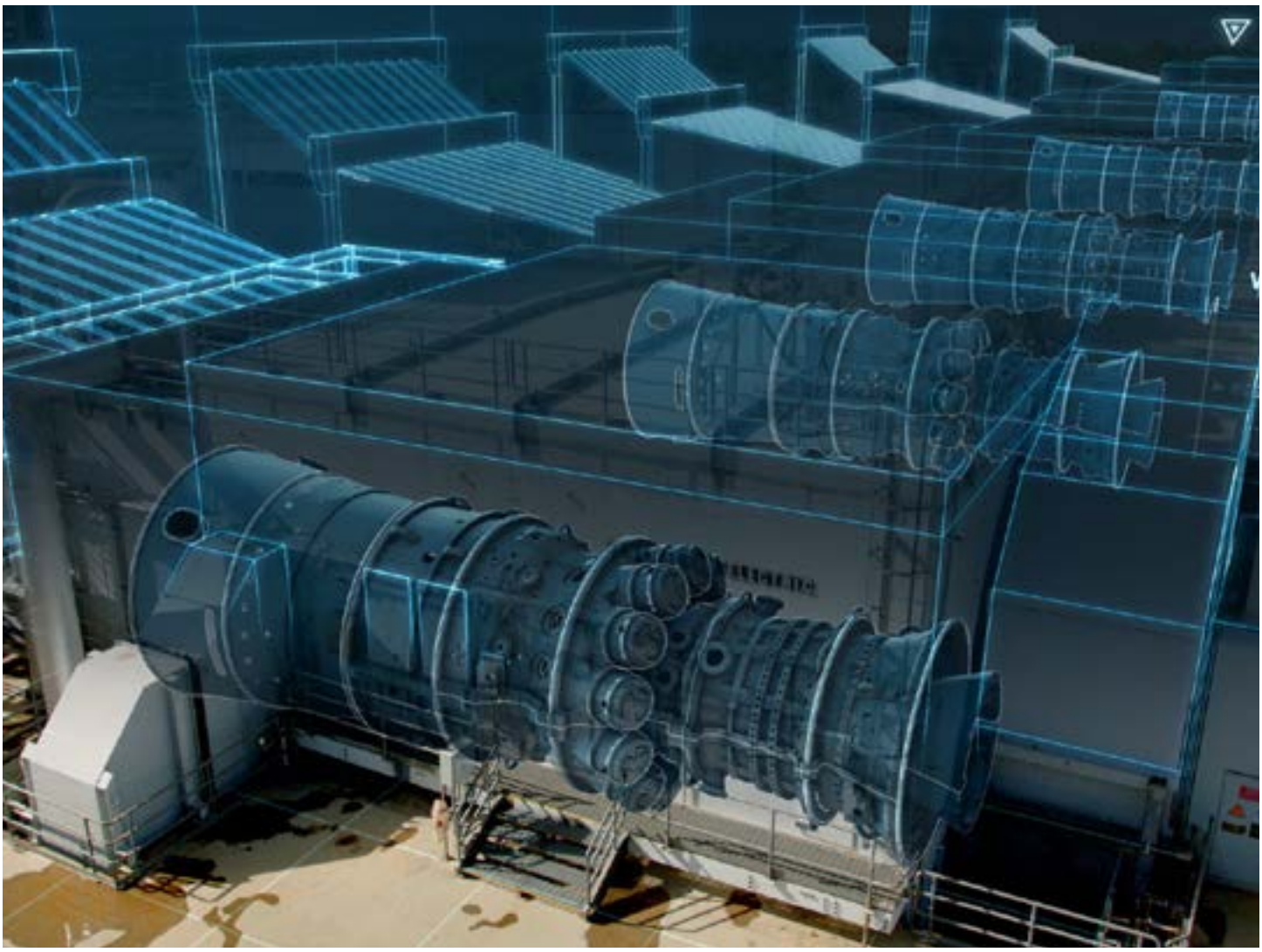
the global fleet of coal and gas-fired power plants, carbon dioxide emissions from power plants would be reduced by 10 percent. That's roughly equivalent to taking all the cars in the United States off the road.

Artificial intelligence is another technology in its early stages of implementation and poised to revolutionize the way energy is produced, transmitted, and consumed. Artificial intelligence and machine learning (ML) could help compress and analyze the massive amounts of data that the energy industry produces so our human decision making will not be overwhelmed by the explosion of data.

There are many different use cases for AI and ML in the energy industry. These include: machines that learn on their own from spotting patterns and anomalies in large data sets; using AI technology to reduce total data center power consumption; and using AI and ML to determine the best generation mix. These will revolutionize both the demand and supply side of the whole energy economy.

GE has employed AI in many aspects of its "digital twin" methodology for using a suite of solutions to provide a digital representation of any physical asset such as a power plant or an aircraft.

GE's digital solutions are already helping many of our customers improve grid utilization by more than 30%, increase renewable energy use by more than 50% and improve reliability by more than 90%. The solutions are also improving power plant reliability by up to 5%, reducing operations and maintenance costs by up to 25%, and reducing greenhouse gas emissions by up to 20%.



The future of energy starts now

The digital transformation in utilities is a long journey that will take the global power infrastructure and its stewards from a reactive mode of operation to a predictive and even autonomous and self-healing framework.

To complete the journey, we will need to take some important steps. We must encourage digital adoption wherever we can, commit to the necessary research and development so new technologies can emerge, fully commit to cybersecurity and data privacy, revise regulatory policy to spur digital transformation, and cultivate the new skills necessary to operate and improve a digitalized energy infrastructure.

As we work towards making this possible, we will continue to balance a bold vision of the future with the pragmatic requirements of helping our customers meet present demands.

As a global company serving over 180 countries, we see ourselves as the world's electricity company. We don't just sell machines, or software, or services: we deliver outcomes — like well-lit classrooms and automated factories of the future. We feel a responsibility to help power schools, hospitals, businesses, and homes around the world. We are proud to be driving the emergence of the twenty-first century global power system. To learn more about GE's end-to-end, integrated, and interoperable energy software solutions, visit our website at ge.com/power/software.

Our digitalized future has just begun, and the best is yet to come.