The global power system is rapidly moving from an electricity system built on traditional central generation with one-way flow to an integrated and hybridized network. These developing networks combine the most efficient central generation and new technologies to provide reliable, affordable, and sustainable electric power for factories, businesses, and communities around the world.

As large, centrally-located power plants become increasingly efficient, we predict that over the next decade, they will be increasingly supplemented by new, often smaller, energy systems that are distributed throughout the system. Known collectively as “distributed energy” technologies, aero-derivative gas turbines, reciprocating engines, energy storage devices, fuel cells, and solar PV systems are being deployed throughout the global power system in greater numbers than ever before.

At the same time, digital tools are being integrated throughout the electricity network — in the generation plants themselves, within fleet and system-wide control systems and across T&D systems. This change is happening against a backdrop of policies designed to decarbonize the electric power system in response to the growing threat of climate change and increasing consumer engagement with digital assets.

Three powerful trends are driving this change: the emergence of digital technologies, the arrival of more affordable distributed energy technologies, and decarbonization through the maturation of renewable energy and energy efficiency options. The convergence of these drivers stands to remake the global power landscape in ways that were once unimagined. They’re also changing the face of electricity customers, as new markets emerge with different needs and preferences.

Other trends are influencing the rise of distributed energy: the growing gap between wholesale and retail prices, which make distributed energy technologies increasingly attractive at the edge of the distribution system; strategically placed distributed energy resources (DER) that provide system-level benefits by increasing grid reliability and deferring T&D costs; and shifting consumer expectations. As distributed energy technologies improve, and empower consumers in other aspects of their lives, consumers in turn have higher expectations. Distributed energy technologies now provide consumers with the opportunity to have direct control in deciding how and when their electricity needs are met.

GE has been a long-time advocate of enabling smaller, decentralized power systems. This is due, in part, to GE’s leadership in developing new and more efficient distributed energy technologies. Today, GE provides a wide range of distributed energy products and services to lead this global megatrend. For example, our microgrid solution is a field-proven, modular and comprehensive...
offering that integrates primary equipment, intelligent controls, and communications with advanced visualization and supervisory control software to monitor, track, and forecast load and generation resources within the distributed energy network. Each GE solution is tailored to the application and the customer’s primary objectives. We are globally recognized for designing, delivering, and servicing customized microgrid solutions for diverse applications. GE is able to offer a comprehensive solution including feasibility studies and network analysis, project management and design, primary and secondary equipment, and controls and advanced visualization tools.

As a global company serving over 180 countries, we see ourselves as the world’s electricity company. And 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, factories, businesses, and homes around the world. Our focus will remain on being a world energy innovation leader by providing technology, solutions, and services across the entire electricity value chain from the point of generation to final consumption.
The way the world distributes power has been evolving for many years. But as the movement gains momentum, the industry is now embracing emerging, distributed, digitally-enhanced, and decarbonized technologies over traditional central generation, transmission and distribution (T&D) technologies.

The global system is rapidly moving toward an integrated and hybridized network that combines the best of existing and new technologies to provide reliable, affordable, and sustainable electric power for factories, businesses, and communities around the world. (Figure 1)

As large, centrally-located power plants become increasingly efficient, we predict that over the next decade they will be supplemented by new, often smaller, energy hardware and software systems that are distributed throughout the T&D system. At the same time, digital tools will integrate with technologies throughout the electricity network — in the generation plants themselves, within fleet and system-wide control systems, and T&D systems. This will occur against a backdrop of policies designed to decarbonize the electric power system in response to the growing threat of climate change.

Three powerful trends are driving this change:

1. The emergence of digital technologies;
2. The arrival of more affordable distributed energy technologies;
3. De-carbonization through the maturation of renewable energy and energy efficiency options.

The convergence of these three drivers stands to remake the global power landscape in ways that were once unimaginied. They’re also changing the face of electricity customers, as new markets emerge with different needs and preferences.

The transformation of electricity is a positive development between people and the planet: increasingly affordable, reliable, more sustainable, and customizable power solutions are now at our fingertips. The collective dynamic of the global electric power system exemplifies the beauty of what Edison started in 1882.
With the addition of emerging technologies like microgrids, the global electric system is evolving toward an integrated, hybridized network that provides reliable, low-cost, and sustainable power to homes, businesses, and factories around the world.

GW values represent rounded 2016 industry orders.

Source: (Owens, Reimagining Our Electricity Future, 2017)
DECENTRALIZATION
GE has been a long-time advocate of moving to smaller, decentralized power systems and storage solutions that meet on-site electricity needs. This is due, in part, to GE’s leadership in developing more efficient technologies along with other manufacturers that produce generation equipment of less than 100 megawatts (MW). Known collectively as distributed energy technologies, aero-derivative turbines, reciprocating engines and solar PV systems are being deployed throughout transmission networks and in remote locations in increasing volumes.

Continued policy support for distributed energy resources, combined with recent innovations and cost declines, have given this trend new urgency, and adoption rates for solar in commercial and industrial facilities are picking up speed. Traditional diesel and natural gas reciprocating engines, including GE’s Waukesha product line, have become more efficient over time. Their small size and dependability make them the generator of choice in many applications around the world, particularly in remote applications. What’s more, small gas turbines continue to show improved performance. Introduced by GE in 1959, the technology has been progressively refined to improve performance and flexibility. Industry orders for distributed reciprocating engines and gas turbines have both reached 50 gigawatts (GW) per year.

Another benefit of distributed energy resources is their ability to meet the heating, cooling, and steam needs of end-users. Many industrial processes require heat as well as electricity as an input into production. Distributed, on-site generators such as reciprocating engines, steam turbines, and gas turbines can supply multiple products to meet customers’ power, heating, cooling, and steam needs. When operating in combined heat and power (CHP) or tri-generation mode, distributed technologies exhibit total efficiencies approaching 90 percent. There is a vast global market for CHP projects. According to the International Energy Agency (IEA), CHP represents 9 percent of the global power generation today. In addition, CHP is a cleaner energy solution for campuses, islands, and cities that can be aggregated in microgrids with advanced digital tools.

Affordable, modular energy storage solutions, such as batteries, also play an important role in the decentralization movement. These solutions enable distributed energy resources to store energy from variable generation sources and discharge at periods of peak demand. The ability to time-shift enables smaller, distributed systems like solar PV to meet a broader spectrum of on- and off-grid customer needs.

DIGITIZATION
The popularity of connected devices, fueled by the affordability of integrated circuits and expanding computing capabilities, has paved the way for sensors with analytics throughout the energy system. The recent challenge has become the analysis of large volumes of data and control of edge assets to turn signal into decision and action.

The Industrial Internet, in particular, opens up a range of applications and potential for optimization across industries. For electricity, Industrial Internet applications have been developed to operate and control T&D networks, to improve the performance of individual and fleets of power plants, and to optimize hybrid microgrid systems. The marriage of the physical and the digital across industries is revolutionizing how machines work and providing cost and resource savings. Recent analysis by GE and Intel suggests that if several of GE’s digital solutions are scaled globally, annual carbon dioxide emissions could be reduced by up to 823 million metric tonnes (mt), equivalent to roughly 45 percent of U.S. power emissions in 2015. Just as individual control systems are critical to the optimal operation of individual assets, digital solutions can now integrate entire power plants and energy systems to maximize their overall efficiency. This approach will grow in importance as assets operating on the grid face growing economic pressure to operate efficiently and economically.
As modern energy systems become hybridized, digitization will become even more important to integrate into the energy system at the T&D level. In the last decade, we’ve seen growing efforts to apply information technologies to the grid to make it “smart” or intelligent. GE is leading the way in expanding the Industrial Internet and developing a new digital grid. The digitization of energy also provides new options for energy efficiency technologies. Sensor-based lighting, smart controls, and a wide variety of new software technologies are helping commercial buildings, retail stores, and industrial facilities transform into intelligent environments. These new kinds of Industrial Internet applications are providing an opportunity to deploy more energy efficient technology within the context of a larger digital productivity ecosystem.

**DECARBONIZATION**

GE, along with like-minded members of the scientific community, business leaders, politicians, and concerned citizens, believes that the consequences of climate change can be addressed through decarbonization of the global energy system. As world carbon dioxide emissions grow, political pressure is leading countries across the globe to enact decarbonization policies. In the United States, gross greenhouse gas emissions have actually fallen due to the transition from coal to gas, wind, and solar. At the Paris Climate Conference in 2015, 195 countries agreed to cut carbon dioxide emissions and review progress every five years.

Beyond climate-specific policies, a broad set of associated policies have been implemented in the last two decades that have already led to sustained decarbonization of the global electricity system, which produces 42 percent of global carbon dioxide emissions. Among the most notable policies are net-metering programs and renewable portfolio standards in the US, feed-in tariffs in Europe, and a potpourri of other subsidies and tax incentives for low-carbon generation sources across the globe. These policies have proven to be advantageous for renewable energy technologies. However, the drive to decarbonize hasn’t simply been about policy push — innovation is also creating technology pull. Over the last decade, the reliability, cost, and performance of renewable energy technologies such as wind power have improved dramatically.

GE’s innovations, along with those of other manufacturers, have helped lower the installed cost of wind turbines, even as greater amounts of electricity are squeezed from a single turbine. The installed cost of solar PV has declined by 58 percent over the past five years due to continued innovation and the rapid expansion of global solar PV manufacturing capacity. This policy push and innovation pull toward decarbonization has resulted in the rapid growth of renewable energy technologies. In 2016, 155 GW of renewable orders were placed globally, of which 74 were solar and 65 were wind, outperforming thermal orders for the first time with a 55 percent share of the total global orders.

The accelerated use of distributed energy resources today is occurring within the context of the broader global power system transformation, which is being driven by the trends of decentralization, digitization and decarbonization.
Three primary drivers are transforming the global energy system: decentralization, digitization, and decarbonization. Together, these factors are shifting the world’s power mix toward smaller, clean, and intelligent technologies like microgrids.

**ENERGY SYSTEM TRANSFORMATION**

Movement toward a digitally enhanced system with low-carbon centralized and distributed technologies.

**DIGITIZATION**

The addition of intelligent control systems and internet-enabled software to optimize plants and the grid.

**DECENTRALIZATION**

The distribution of small-scale generation throughout the T&D network.

**DECARBONIZATION**

The rapid deployment of low-carbon technologies such as wind and solar.

Source: (Owens, Reimagining Our Electricity Future, 2017), Figure 4
WHAT IS DISTRIBUTED ENERGY?

Distributed energy systems are small, decentralized electricity generation and storage systems that meet the local electricity demand of residential, commercial, and industrial facilities. Distributed energy systems can be made up of a single technology — like a diesel or gas genset — or they can be hybridized by combining several technologies such as solar power and energy storage technologies. These systems are often tied together and operated collectively to meet local demand using a digital control system. Although definitions vary, a digitally-control hybrid distributed energy system can be considered a microgrid if it has the ability to “island” or disconnect from the utility grid. Distributed energy systems can be connected to the local T&D network, they can be off-grid, or they can have a grid connection along with the capability to disconnect from the grid entirely. (Figure 3)

There are many advantages to distributed energy resources compared to larger, centrally-located power plants. Because of the accelerated build time, smaller size, and modular nature, they enable homes, offices, and factories to meet their own electricity needs directly using technologies that are sized and configured in a manner that matches local requirements. They can be configured to provide electricity only, or they can be configured to also meet local demand for steam, heat, or cooling. For end-users without access to the electricity system, or those that are in regions with unreliable grid power, distributed energy resources represent an opportunity to secure reliable electricity. Further, because there is a range of distributed energy technologies, including reciprocating engines, gas turbines, solar PV panels and small wind turbines, distributed energy resources can be configured in a way that meets both the energy and environmental requirements of end-users.

Distributed energy systems are widely used in both grid-connected and remote applications across developed and developing economies. In developed economies with legacy T&D systems, distributed energy resources are used to power communities and cities, industrial facilities, commercial complexes, and residential communities, as well as campuses such as colleges, universities and hospitals. In these applications, end-users typically have access to the local power network. Here, distributed energy resources are used to supplement the grid or provide solutions that reduce costs relative to utility-supplied power. Distributed energy systems also are an increasingly popular solution for military bases that want the option to draw power from the grid or operate in island-mode. In many parts of the developing world, T&D systems are either not available or are often less reliable. Here, grid-connected microgrids are used to provide reliable electricity where it is needed. Furthermore, remote microgrids enable electricity to be made available in areas beyond the reach of the grid. Distributed energy systems are being widely adopted on islands and archipelagos, where electricity networks are not available or are weakly connected.
DISTRIBUTED ENERGY ON THE RISE

As discussed, the accelerated use of distributed energy today is driven by three trends: decentralization, digitization and decarbonization. But they aren’t the only motivating factors. We’ve identified additional drivers that are making a big impact on the global power system:

- A rate gap between wholesale and retail: Even though wholesale electricity prices are lower in some regions because of declining fuel prices, retail electricity rates have been slow to keep pace. Additionally, legacy and new T&D costs continue to prop up retail electricity rates. This has created a growing gap between wholesale and retail prices, which make distributed energy technologies increasing attractive at the edge of the distribution system.

- The growing importance of system-level benefits: Strategically placed distributed energy resources provide demonstrated system-level benefits by increasing grid reliability and deferring grid upgrade costs.

The system-level benefits provided by distributed energy are becoming more important in geographies with legacy T&D systems. In these systems, distributed energy provides a viable non-wire alternative to T&D system upgrades.

- Higher consumer expectations: Electricity customer expectations and needs have risen as distributed energy technologies have improved and as the digital technologies have empowered them in other aspects of their lives. Distributed energy technologies provide consumers with the opportunity to control their electricity needs and provide a customized solution.

Furthermore, the rise of distributed energy is buoyed by the widespread availability of distributed energy technologies and their increasingly attractive economics. Although the cost and performance of all distributed energy resources has continued to decline over time, solar photovoltaic technologies and batteries have experienced the greatest cost declines.
For example, falling battery costs make energy storage an increasingly attractive option in microgrid systems. According to Bloomberg New Energy Finance, the average global price of lithium-ion battery packs has fallen by 80 percent since 2010, from a price of $1000/kWh in 2010 to $209/kWh in 2017. As a result, a record 1.2 GW of battery storage capacity was installed in 2017, up from just 139 MW just five years earlier. (Figure 4)

Likewise, the cost of solar PV technologies has declined dramatically. In 2010, the average cost per watt of a PV system in Germany was $3.90, but by the end of 2017 it had fallen 57 percent to $1.68. Prices varied for different types of modules in different regions of the world, but the overall direction since 2010 has been downward by 50 to 75 percent. (Figure 5) Industry analysts expect modules to drop by another 15 percent in 2018 as more manufacturing comes online. As a result of these cost declines, distributed solar PV installations have risen dramatically since 2010 growing from tenfold from 17.3 GW in 2010 to 173 GW in 2017.iii

The global distributed energy market is responding to these drivers with increased expansion. According to Navigant Consulting, the collective group of distributed energy technologies, including distributed solar PV, small and medium wind turbines, microturbines, fuel cells, natural gas gensets, diesel genset, distributed energy storage, and microgrids had an installed capacity of 94 GW in 2017. As a group, the installed capacity of these technologies is expected to double by 2026. The annual average growth rate of these technologies is estimated to be 7.7 percent between 2017 and 2026. (Figure 6)
Figure 6: Installed Distributed Energy Capacity (2017-2026)

The installed capacity of these technologies is expected to double by 2026. The annual average growth rate of these technologies is estimated to be 7.7 percent between 2017 and 2026. Distributed solar, diesel gensets, and microgrids are expected to add the most capacity during this period. Over 12 GW of new microgrid capacity will be added during this time.

Between 2017 and 2026, the annual average growth rate of these technologies is estimated to be **7.7%**
THE HISTORY OF DISTRIBUTED ENERGY

Distributed energy resources are not an entirely new platform. Small, distributed power plants have been available since the beginning of the electric power industry at the end of the 19th century. By the 1980s, power companies began coupling distributed power technologies with digital controls systems. The recent emergence of highly-sophisticated and lower cost digital control systems, coupled with rapid reductions in the cost of distributed renewable energy resources and energy storage solutions has created a surge of new microgrid development in the 21st century. (Figure 7)

Before the development of large-scale power plants in the early 20th century, all energy requirements — including heating, cooling, lighting, mechanical, and electric power — were supplied at or near the point of use. Technology advances, economies of scale and a regulatory framework that supported central power enabled the growth of large power plants. The first power plant, Thomas Edison’s Pearl Street Station, began supplying power in September 1882 in New York City. Edison’s reciprocating engines at Pearl Street were steam engines, a technology developed by James Watt 100 years before for mechanical drive use. The internal combustion engine wasn’t invented until after Pearl Street. Pearl Street was a direct current (DC) distributed power system that served the needs of nearby customers, like all of the early power plants built by Thomas Edison’s company, Edison General Electric. General Electric was formed through a merger of Edison General Electric and Thomson-Houston Electric Company in 1892. Further advances in alternating current (AC) technology would be required before anyone could build larger power plants and the electrical output could be distributed to far-flung customers over high-voltage transmission lines. The Pearl Street Station was composed of six reciprocating engines, each connected to a 12-kilowatt (kW) generator to yield a total capacity of 72 kW. After the Pearl Street Station, the amount of electricity that could be produced by a single power plant grew quickly. The development of ever larger power plants was facilitated by Charles Curtis’s steam turbine. Mr. Curtis presented the concept of a generator driven by a steam turbine to GE management in 1896. By 1897, he was directing steam turbine development for GE.

The Move to Central Station Power

The movement to central station power plants started in earnest in 1891, when George Westinghouse assembled the first AC system in Telluride, Colorado. The AC system enabled the transmission of power over long distances. This resulted in the development of ever-larger power plants with increasing economies of scale. Lower power production costs were realized in the process. By 1922, 175 MW power plants were being constructed. The era of central station power was underway, and distributed power technologies were consigned to providing back-up and remote power.

Early Innovations in Distributed Energy

The invention of aeroderivative gas turbines signaled the very beginning of the shifting tide in the way power is produced. After having specialized in jet engines for over a decade, GE introduced its first aeroderivative gas turbine, the CF6, for hydrofoil vessels in 1959. CF6 was a derivative of GE’s J79 and C6 jet engines. Since the introduction of its aeroderivative product line in 1959, GE has progressively refined the technology to improve performance and flexibility. In 1985, GE’s aeroderivative CF6 line had a maximum power output of 35 MW. Today, the CF6’s descendants offer output in the 60 MW range with efficiencies higher than 40 percent and reliabilities approaching 97 percent. Today, GE aeroderivatives are the world’s leading technology for industrial power use. More than 3,600 turbines have been produced, logging more than 100 million operating hours. Reciprocating engines have followed the same path as aeroderivatives. Reciprocating engines have been commercially available since the late 19th century. After the emergence of large central station power plants in the first decade of the 20th century, reciprocating engines were used primarily in automobiles and as a backup and remote power source throughout the first half of the 20th century. However, incremental innovations over the last
Distributed energy resources like microgrids are not new. Small, distributed power plants have been available since the beginning of the electric power industry at the end of the 19th century. By the 1980s, power companies began coupling distributed power technologies with digital controls systems. The recent emergence of highly-sophisticated and lower cost digital control systems, coupled with rapid reductions in the cost of distributed renewable energy resources and energy storage solutions has created a surge of new microgrid development in the 21st century.

**Figure 7: Distributed Energy Timeline, 1880-2018**

Distributed power plants accounted for 100% of global electric capacity additions in 1900. By 1950, distributed power technologies accounted for less than 10% of global electric capacity additions. Distributed power was limited to back-up gensets and transportation applications. By 2010, distributed power technologies accounted for 36% of global electric capacity additions.

- **1882**
  - Thomas Edison’s Pearl Street Station distributed power plant began supplying power in New York City.

- **1893**
  - Rudolf Diesel develops the Diesel engine.

- **1900–1950**
  - GE placed its first steam turbine into operation in 1901.
  - By 1902, GE offered turbines with rated capacities of 500, 1,500 and 5,000 kW.
  - By 1913, the largest generator in the United States was 35 MW.
  - By 1922, 175 MW power plants were being constructed.

- **1950–1960s**
  - In 1957, Jenbacher began producing gas engines.
  - In 1959, GE introduced its first aeroderivative gas turbines that were derivative of GE’s J79 and C6 aircraft engines.

- **1994–2012**
  - Jenbacher begins focusing on ultra-high efficiency engines. The newest gas engine delivers up to 9.5 MW with an electrical efficiency of 48.7% and a CHP efficiency of over 90%.

- **2010**
  - GE’s aeroderivative portfolio includes turbines with power output from 18 to 100 MW with thermal efficiencies over 40%.
  - The global emergence of increasingly economic distributed solar power technologies.

- **2010-2020**
  - Acceleration of Internet of Things (IoT) and the digitization of energy.
  - The emergence of distributed integrated systems with digital controllers.

- **2020**
  - Increasingly economic energy storage systems emerge.

Source: (Owens, The Rise of Distributed Power, 2014), Figure 3
50 years have resulted in the development of flexible, high performance, and low emissions gas and diesel engines across a range of applications including power, marine, and mechanical drive.

Renewable power technologies have become cost competitive over time and more grid-friendly and compatible with the electric power system, which has accelerated their use in microgrid systems. The largest cost reductions have come from solar photovoltaic (PV) technology, which has experienced an 80 percent cost decline in the last decade. New technologies that incorporate energy storage to reduce the impact of variability from wind and solar PV technologies, as well as the addition of digital technologies that ensure the renewable power system are fully optimized, will continue to push down the cost of renewable energy.

Software has been used in industrial processes since 1959. That’s the year that Texaco’s Port Arthur refinery became the first chemical plant to use digital control. The Port Arthur refinery used an RW-300 mainframe manufactured by Ramo-Wooldridge Corporation and led the way in the development of industrial computer control. Since that time, software has become increasingly integrated into industrial machinery. Digital technologies have been applied to power plants since that time. These systems became increasingly sophisticated in the 1980s, and information technology advances enabled digital controls to be applied to small, remote microgrid systems. This enabled on-site operational optimization for the first time. More recent information technology advances have reduced costs, increased capabilities, and provided Internet-connectivity to distributed power control systems.

The history of distributed power within the electric power systems highlights the fact that the global power system unfolded in three eras: The Distributed Power Era (1890–1910), the Central Station Power Era (1910–2000) and the Integrated Energy Systems Era (2000–present). Unlike previous eras, where either distributed or central power systems dominated the landscape, today’s Integrated Systems Era is characterized by a combination of central station plants and distributed energy resources that can operate in isolation or together within increasingly integrated and digitally-enabled energy networks. (Figure 8)
Unleashing the full potential of microgrids requires reliable information technology (IT) systems. Blockchain technology presents an exciting opportunity for decentralized energy environments to enable, validate, record and settle energy transactions in real-time.

Blockchain is a distributed digital ledger built on a decentralized transaction verification system that could enable peer-to-peer transactions, where neighbors transact directly with each other and trade energy generated from their rooftop solar panels and electric vehicles through the microgrid. Utilities may not be needed to serve as an intermediary.

Microgrids require bi-directional flow of energy amongst multiple nodes. This means balancing supply and demand, as well as tracking and executing large transaction volumes. These challenges may be well suited to the attributes of blockchain technology.

The decentralized peer-to-peer and real-time capabilities of the blockchain could unlock new pricing and business models of microgrid networks. Smart contracts on the blockchain could allow real-time automated exchanges between neighbors buying and selling power on a pay-per-use basis.

While peer-to-peer transactions could open doors, it’s not the only application that could be unlocked. The fundamental question is who manages financial transactions on the microgrid? Is it independent system operators, utilities, or prosumers? Depending on the stakeholder perspective, there could be three types of applications and transaction models between electricity buyers and sellers: utility microgrid transactions, wholesale microgrid transactions, and peer-to-peer microgrid transactions.

Pairing blockchain technology with microgrid applications could offer several benefits, mainly lowering energy costs. Distribution costs could be reduced with the deployment of microgrids. And capacity costs could also be reduced when blockchain enables demand response programs across microgrids which may require less back-up generation.

It’s important to recognize, however, that blockchain technology is still in its early days. There are obstacles to overcome, including government regulations and technical challenges. Faster transaction speeds may be required, and reduced energy demand for blockchain operations will be needed to scale. More clarity is expected on the prospect of blockchain microgrid applications as ongoing industry pilots start showing results and outcomes are shared across the industry.
Electric power networks across the globe are undergoing transformation. Distributed energy resources are at the center of this change.

The traditional methods of power production and distribution established almost a century ago are being challenged, as the focus shifts from the ability to socialize the cost of service over a wide customer base via volumetric rates to emerging technologies, particularly distributed energy resources and microgrids, progressive regulatory policies and shifting customer expectations. This has led the industry to rethink the traditional role of distribution utility and the business and regulatory models that support it. A recent survey of electric utility executives by Utility Dive confirmed three salient points: (1) the industry’s three most pressing challenges are old infrastructure, an aging workforce, and the current regulatory model; (2) utilities will move away from the traditional vertically integrated utility model towards a more distributed, service-based model; and (3) utilities see a big opportunity in distributed energy resources but are unsure of the best business models.

Two examples of this evolutionary thinking include recent legislations passed in New York and California. In California, the California Public Utilities Commission (CPUC) issued a mandate for regulated utilities to develop Distribution Resource Plans (DRP) to accommodate and integrate distributed energy projects into their system planning and operation procedures. In New York, the NY DPS has pushed a “Reforming the Energy Vision” (REV) initiative that redefines the role of the distribution utility as a service provider, and facilitator of customer-based services. Within these two states and many others at the forefront of distributed energy penetration such as Hawaii, Texas and Arizona, utility executives and engineers are wrestling with tough questions, such as: How much distributed energy can I accept and still keep the lights on? How can I be proactive about distributed energy resources? What is the true value of solar? Where am I most at risk to lose customers? How do I sustain my business and make a profit in this new paradigm?

In this context, there are four key stakeholder groups with different, sometimes conflicting, goals and objectives:

1. **Utilities**: Utility leaders are trying to understand how integration of microgrids and distributed energy technologies changes their business model and what are the keys to their survival.

2. **Regulators**: Regulators are tasked with designing policy frameworks that facilitate or accelerate adoption of new technologies and services in a financially and socially equitable way.
3. Developers: Developers seek to understand the economics and long-term viability of potential microgrid and distributed energy projects and select the best locations and technologies to maximize revenues.

4. Vendors and consultants: These groups are interested in developing offerings and position their products and services for this emerging market segment.

The changing energy landscape encompasses multiples priorities — the increased penetration of distributed energy technologies, including renewable energy and storage, and deployment of microgrid systems to the grid. Distributed energy development in particular represents a disruptive approach to energy delivery for a subset of customers, allowing customers to essentially bypass the electric utility and produce, store and deliver electric and thermal energy locally, reducing the impact of grid-related events.

**DISTRIBUTED ENERGY APPLICATIONS**

Distributed energy systems are used for a variety of reasons, and the primary purpose depends upon the application. In this section, the focus is applications for microgrid systems. Recall, microgrids are digitally-controlled hybrid distributed energy systems that have the ability to “island” or disconnect from the utility grid. Military, industrial, island, and institutional users all have different priorities, but the most common drivers are: energy surety, reliability, sustainability, and economic value. (Figure 9)

Commercial and industrial (C&I) customers are more sensitive to the price of energy. As such, they’re motivated to take advantage of efficient distributed generation, combined heat and power (CHP) solutions, energy storage demand response, and controllable loads. These efforts help reduce year-round energy consumption, lower and shift peaks to avoid demand charges, improve load factor, reduce reactive power demand, and take advantage of market opportunities to derive revenue.

Reliability and resiliency are also key drivers for C&I facilities, as well as critical infrastructure such as hospitals, emergency response (fire, police, etc.), water treatment plants, emergency shelters, and other public safety institutions. When industrial and manufacturing companies lose power, it can cost millions of dollars in downtime,

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**Figure 9: Microgrid Applications**

Microgrids, or distributed energy systems that have the ability to stand-alone, are used for a variety of reasons. The primary purpose depends upon the application. Military, industrial, island, and institutional users all have different priorities, but the most common drivers are: energy surety, reliability, sustainability, and economic value.

- **Energy Surety**: Military Bases with critical infrastructure
- **Reliability**: Industrial Mining/refineries Ports
- **Sustainability**: Islands Remote grid communities
- **Economic Value**: Institutional / District University/labs Hospitals Utility microgrids

*Source: GE Energy Consulting*
waste and equipment damage. Deployment of distributed energy resources at or near the plant site enables industrial customers to continue operating even if the main grid is down, contributing significantly to economical plant operation.

As a result of several high-profile storm events within the past few years, the state of New York and several other Northeast states have developed policy initiatives to incentivize distributed energy and microgrid deployment at critical facilities within communities across the states. In the New York Prize program, and several New York REV demonstration projects, microgrid and behind-the-meter distributed energy projects are specifically required to improve resiliency for critical facilities, and well as demonstrate positive benefit/cost impact. Similar programs in New Jersey, Massachusetts and other nearby states are using state directives and subsidies to demonstrate applicability, scalability, and replicability of microgrid projects in communities across the states.

For example, in the town of Postdam in Upstate New York, the local utility is working with a team of consultants to determine if a microgrid is technically and economically feasible to provide improved reliability and resiliency to an area that typically experiences severe winter storms leading to outages that put the community and its residents at risk. GE’s Energy Consulting business partnered with National Grid, Clarkson University, and Nova Energy specialists to engineer the technical and economic designs for the resilient microgrid for the community under the NY REV program. The design included: business case development and ownership model; distributed energy selection, siting and sizing, dispatch modeling; distribution network design, steady-state and stability studies; controls and communications design; and benefit/cost analysis.

The need for energy independence, particularly for military installations and critical facilities, is a major driver of distributed energy and microgrid implementation on military bases and other facilities to reduce dependence on local supply and fossil fuels, increase renewables penetration, and significantly reduce consumption. For example, for its military bases, the United States Naval Command set goals to reduce energy use by 3 percent per year, reduce annual petroleum consumption by 20 percent, and derive 50 percent of energy from alternative sources by 2020. These high-level goals have led to many projects to redesign base energy supply and delivery systems and incorporate sophisticated control systems to dispatch and optimize performance in both connected islanded modes.

For some college campuses, C&I facilities, municipalities and communities, environmental consciousness and the desire for sustainable energy has led to greener designs and systems optimized to reduce energy consumption and peak demand. These systems can often justify inclusion of energy storage to facilitate renewables integration, particularly PV and other “clean” energy resources such as small hydro and some gas reciprocating technologies with heat recovery. This has led to a segment of microgrid projects that link multiple facilities and distributed energy through a private power delivery network, with one or two points of interconnection (POI) to the utility system. Such a configuration typically allows the campus or community to run as a virtual energy island, exporting/importing power via the POI(s), and providing ancillary services to the market to offset capital and operating expenses. An example of this type of microgrid is the Aries Power’s Albany University Heights project under NY Prize. The design includes several major institutional customers, Albany Law School, Albany College of Pharmacy and Health Sciences, Parson’s Child and Family Center, Albany Medical Center South Clinical Campus, and the Capital District Psychiatric Center (CDPC) linked via a dedicated underground distribution network to route power from gas-fired CHP, fuel cells, solar PV, and battery storage to load centers to facilitate a sustainable, economic micro-system.

Globally, the rise of microgrids and distributed energy is spurred by necessity, rather than choice. Many communities that are remote from a central grid have no choice but to develop their own sustainable power systems that can operate in isolation and drive economic development for the region. This is the case in many Southeast Asian and African countries where most of the population remains
unelectrified due to the slow expansion of urban grids. Distributed energy systems based on a combination of diesel gensets, solar PV and battery storage have become a popular option to power remote villages and provide sustainable power as the grid expands to meet them. Remote off-grid systems are also often necessary in mining operations, and gas exploration sites in many global regions such as eastern Europe, central Asia, Africa, Alaska and Canada. What these installations have in common is an economic driver for power in the absence of other viable alternatives.

Many small island systems are also natural microgrids. Because they incorporate multiple distributed energy technologies and dispersed loads on a local grid, they can be disrupted by high penetration variable generation. The optimization and control inherent in microgrid control systems is being applied to promote a more sustainable mix of resources, and improve the stable, economic operation of small island systems.

**Lessons Learned**

GE Energy Consulting has been at the forefront of designing microgrids and studying the technical and economic feasibility of integrating microgrids into existing power systems. While individual microgrid studies can provide various insights specific to the unique application examined, there are common factors that span our work that can and should be considered. The first thing to know is that technical and economic feasibility studies require financial and time commitments. High-level and back-of-the-envelope calculations may help but cannot provide the breadth of insights that a full-fledged study can — such as ideal microgrid structure and layout, size, costs, and potential challenges. These insights can lead to significant cost savings during detailed design and implementation. In our work, we have encountered various challenges, determined best practices and learned many invaluable lessons that can help ensure those looking to incorporate microgrids make informed decisions and set themselves up for successful implementation.

Developing an economically sustainable business structure and business model can be complex. Much like any other initiative, return on investment (ROI) is a substantial factor in microgrid implementation. ROI doesn’t just have to be a monetary improvement, it could also be in the form of increased availability and flexibility for the broader grid, or any number of other benefits.

When starting to plan for a microgrid implementation, utility support is essential. Collaboration can help ensure a reliable electrical system design and provide mutual benefits. For example, leveraging existing generation and distribution systems could help reduce technical complexities and reduce investment needs, and higher values can be accrued to microgrids if they also help defer utility expenditures on substations or T&D and if they contribute to system reliability and service quality. Distributed energy value propositions also can be improved with participation of microgrid assets in the utility demand-response programs and independent system operator capacity, energy and ancillary markets.

There also are numerous tradeoffs that should be examined when deciding on the structure of a microgrid and what assets to implement. If the decision is made to include renewable energy into the generation mix, there may be more capital investment required upfront, and with the inclusion of renewable generation, energy storage should also be part of the discussion in order to firm up the renewable energy availability during larger grid outages. While these aspects are likely to increase the investment needed to implement a microgrid, they can also provide the societal benefit of reduced environmental impact. Other societal benefits that can and should be weighed in decision-making are those associated with improved uptime of critical facilities—such as hospitals, emergency shelters, first responders, police, fire, water and sewer services, and so on.
GE MICROGRID SOLUTION

GE’s microgrid solution is a field-proven, modular and comprehensive offering that integrates primary equipment, intelligent controls and communications, with advanced visualization and supervisory control software to monitor, track, and forecast load and generation resources within the microgrid network. Each solution is tailored to the application and the customers’ primary objectives.

Consulting services include:
- Technical and economic feasibility studies
- Business case development
- Detailed engineering designs
- Grid interconnection studies
- Protection and controls

The system components include:
- Energy storage solutions
- Microgrid control system and communications
- Microgrid Energy Management System
- Inverters and Balance of Plant
- Generation solutions – gas, hydro & wind
- Services (engineering, project management, installation and commission, maintenance and asset performance management services)

Typical applications include:
- Utility
- Remote communities
- Military
- Community and smart cities
- Industrial
- Campus

The solution can be delivered as:
- Supplying equipment
- Engineered packages
- Full Engineering, procurement and construction
GE ADVANTAGE

GE is globally recognized for designing, delivering and servicing customized microgrid solutions for diverse applications. GE is able to offer a comprehensive solution including feasibility studies and network analysis, project management and design, primary and secondary equipment, controls and advanced visualization tools. Working with GE, customers can realize the following business outcomes:

- **Improve grid reliability**
  With GE’s uniquely designed solution for grid resilience, energy and system reliability

- **Reduce operating expense**
  Advanced operation controls for energy bill reduction, demand response efficiencies and power mix optimization

- **Improve financial performance**
  Monetize the value of assets through new revenue streams

- **Increase operation efficiency**
  Single platform for managing grid assets, generation assets, customers (loads), markets and other counter-parties

**Integrated, tailored solutions**
from consulting services to system optimization
Microgrids are an important part of the rise of distributed energy. Because they are customer-sited and custom-tailored to meet end-user energy needs, designing them is a challenging process.

There are three primary steps involved in the design: feasibility assessment, preliminary technical design and detailed design. (Figure 10)

**FEASIBILITY ASSESSMENT**
The first step in the design process is to assess the technical, commercial, and financial feasibility of the project starting with a clear justification driving the need for the microgrid. The questions that need to be considered in this stage are:

- What is the purpose and need for this project?
- What are the objectives of the project?
- What will be the impact of the project on the community?
- What value can the project bring to the interconnected utility?
- What are the expected benefits?

A typical feasibility study includes an exploratory assessment of the key aspects of the project, such as:

- A technical and operational feasibility study that includes an assessment of the customer load that has to be met by the microgrid; the generation, energy storage, energy efficiency, and demand response resources required; requirements for additional electrical and communications infrastructure; as well as a general idea of how the microgrid would operate under blue-sky conditions and after major system events.

- A commercial feasibility study identifies direct services generated by microgrid operation, such as ancillary services, and indirect benefits, such as improved operation to the utility.

- A financial feasibility study that includes an identification of the categories and relative magnitudes of the revenue streams and/or savings, as well as capital and operating costs that will be incurred by the microgrid owner.

- A legal feasibility study that includes the development of potential project ownership structure and the legal terms/conditions/requirements necessary to develop and operate the microgrid.
Permitting, siting, and regulatory feasibility for determining the permits and/or special permissions that will be required to construct the project, as well as any anticipated or potential regulatory hurdles.

The feasibility assessment also typically includes a benefit/cost analysis in which the expected benefits of the project are weighed against its costs.

**PRELIMINARY TECHNICAL DESIGN**

The feasibility study is typically followed by a preliminary design of the microgrid. In this stage of the design process, a preliminary technical design of the microgrid is developed.

**Site Characterization**

Site characterization is the essential first step in preliminary design. It involves a thorough data collection on all pertinent aspects of the distributed energy, including: electrical and thermal load of the facilities within the distributed energy; information on any existing distributed energy assets, renewable resources, energy storage, and demand response; and the underlying electrical and information network. The site characterization involves a thorough characterization of the mission, site, existing electrical, control and IT infrastructure, existing loads, existing generation, fuel supply, as well as the electrical rate structure.

**Component Selection**

Component selection and sizing defines the distributed energy system. The selection process includes an electrical and thermal load and supply analysis in order to determine the additional supply side and demand side resources needed in the distributed energy and their proper sizing.

A key aspect of this task is the load and supply analysis. Load and supply analysis can be a model-based determination of the various distributed energy elements...
in order to meet the customer's electrical and thermal requirements (i.e., heating and cooling loads) reliably during emergency periods (i.e., grid outage) and normal days, and also provide the most economic combination of internal electrical and thermal generation and electrical purchases from the grid during normal days in grid-connected mode.

This stage also involves the development of a functional design of the microgrid that identifies various DER resources included and lays out the electrical network infrastructure and also the control and communications infrastructure.

DETAIL DESIGN

The detailed technical design is the final step in the design process for developing the blueprint for the microgrid. The objective of this stage is to develop an audit-grade design that can be used for procurement.

This stage will build on the data gathered and analysis performed in the feasibility and preliminary design stages. Power quality analysis as well as load characterization is performed to characterize the load served by the microgrid in islanded and grid-connected modes. Loads are typically categorized for criticality (L1-L4) and also analyzed for content (lighting, heating motors, etc.). The transient behavior of loads that are a part of the microgrid are also analyzed through in-depth analysis such as motor starting studies. This stage also involves the design of load-shedding schemes based on the criticality of loads in the microgrid.

In the detailed design stage, the load and supply analysis performed earlier is fine-tuned using more accurate and granular information of the load. Detailed specifications including ratings for each component of the microgrid, along with how each component interacts with the rest of the microgrid are developed. Any measures for infrastructure hardening that will improve the electrical infrastructure’s resiliency to inclement weather and environmental conditions are also developed.

This stage also typically involves several in-depth studies for designing the power distribution system such as steady-state load flow analysis, short circuit and protection study, system dynamics study, harmonics and flicker study, as applicable. Various functional requirements for the microgrid controller such as microgrid monitoring and protection, fault response, voltage and frequency control, DER optimization and dispatch are developed. Use cases developed during this stage cover all the key control and management capabilities of the microgrid under normal operation or during disturbances.

The communication technology and architecture, including integration with external systems such as building & lighting management systems, cyber-security, hardware and software requirements, as well as protocols and data exchanged between the various layers of the MG, are also developed in this stage.

A microgrid can be built to a variety of scales and classes and can serve multiple different operational objectives. Microgrids are much more than islanded power grids, or distributed generation, or simply another electrical node connected to the grid. A microgrid is a system of highly integrated components and comprises both information systems technology and power systems technology. The sophistication and breadth of technology applied within the microgrid, and the amount of integration required with external systems, will differ based on specific use case. Some microgrids will scale heavy in supporting energy management software and communications and others will be minimized electrical systems. While the design of the electrical infrastructure is already well established in the power industry, the design of the IT infrastructure is new to most practicing power engineers. Developing this type of intricate and integrated grid management system requires the application of system-architecture based methods and design processes to ensure a robust assessment of the operational objectives and a methodical decomposition of a system’s requirements into a compliant microgrid system design.
An important part of the process of developing a DER is making the business case to decision makers. This involves several key issues including business models, ownership issues, governance structure, financial analysis, and social benefit/cost analysis. This section will discuss the important elements of making the business case, with a specific focus on microgrid systems.

**BUSINESS MODEL ISSUES**

The main issue of concern to the utilities and potential distributed energy developers is the underlying business model of the distributed energy. There are many open questions. For instance:

- Who would own and operate the distributed energy system?
- What is the role of utilities in terms of ownership and operations?
- Can distributed energy systems be economically viable under current regulatory and pricing regimes?
- What are the potential revenue streams?
- How should costs and revenues be allocated between various stakeholders?

Currently, many state commissions, utilities, and other stakeholders are working to address these and similar questions. A universal distributed energy business model and governance structure that can be replicated and scaled for application to a wide range of distributed energy resources is still in development. It is quite possible that a one-model-that-fits-all may not exist, and each individual distributed energy resource may end up having its own customer tailored business structure based on its location, characteristics, and the regulatory and policy environment where they operate.

**Ownership Issues**

In addition to the question of economic viability, the most critical issue appears to be utilities’ role in owning and operating the distributed energy system. The current regulatory structure and the business model of the utilities are not totally conducive to natural development of distributed energy resources, unless there is a pressing need for reliable uninterruptible power for critical services where economic viability is not a decision factor.

Under the traditional regulatory regime, increased distributed energy resources would have an impact on consumers similar to solar PV. When solar use went up, utilities lost revenue and passed losses on to non-solar customers by way of rate increases.
To address this issue, it may be necessary to make changes to utility business models and the regulatory structure that defines their obligatory services and governs how they get compensated for those services. A possible solution is a change to the utility rate-making process. Such changes may not be possible in the short term, however.

Another possibility is allowing utilities to directly own and operate distributed energy assets and provide distributed energy services (mainly, resiliency during emergencies) to their customers. However, utility ownership of distributed energy assets is assumed to be problematic since it extends the natural monopoly position of the utilities and creates a conflict of interest situation by creating the potential for utilities to give their own interests priority over their customers’ interests.

It can be argued that the natural monopoly of utilities can be extended to the underlying distribution assets — i.e., the electric network and feeders that directly connect microgrid loads and distributed energy assets — but not to the distributed energy assets themselves. A grid-connected distribution system requires a utility’s jurisdiction to ensure the network’s reliable operation, needing the same care and attention paid to other utility distribution assets. Consequently, a reasonable path forward seems to be bifurcated ownership and operation of the distributed energy assets, with utilities owning and maintaining the distributed energy electrical and other non-utility stakeholders owning the distributed energy assets.

Other special services that utilities can provide include metering and billing services for the customers and also for the distributed energy entity. One other possible role for the utility is maintaining and operating the distributed energy management system and controller in order to ensure reliable operations of the distributed energy assets, assuming conflict of interest issues can be properly addressed.
**Governance Structures**

There are different views on possible business models and governance structure for distributed energy resources, but in most cases, unless all of the distributed energy is behind a meter or totally off-grid at all times, the expectation is that the utility will own and operate the underlying distributed energy electrical network. Examples that are more relevant to microgrids include:

- Utility acts as a Central Procurement Entity: Utility would have a contract with customers through PPAs and offers other services such as billing and hosting the distributed energy controller. This model raises questions of market power by utility.

- Distributed Energy Provider: Distributed energy generation assets are owned by an entity, which could be a consortium of underlying loads. Distributed energy electrical network and distributed energy controller is owned and operated by the utility. This model enables distributed energy load and generation facility owners to be direct stakeholders in the distributed energy ownership and operations.

- Distributed Energy Service Company (DESCO): A third party, similar to Energy Service Companies, but with distributed energy asset ownership, has contracts with customers to provide power and services during normal (grid-connected mode) and emergency/outage periods (islanded mode). The advantage a DESCO will have over ESCO is the distributed energy asset ownership, which enables DESCO to hedge against market prices when prices are higher than DESCO’s on-site generation.

- Special Utility District: The whole of distributed energy system, including its distribution system, operates as a special utility district (SUD) which in turn would be a form of special purpose vehicle/entity (SPV/SPE).

**Financial Analysis**

As any business proposition, a fundamental requirement for developing distributed energy resources is their economic viability. Economic viability for the distributed energy developer and owner/operator is interpreted as the potential for making profit as an ongoing business concern, based on a detailed financial analysis that takes into account all the capital and operating costs and all the potential revenues.

**Societal Benefit/Cost Analysis**

Some distributed energy resources, such as those intended to be operated as resilient distributed energy resources, namely the ones that are designed to provide uninterrupted power to a collection of interconnected critical loads during emergencies and outages of the larger grid, have a societal aspect to them based on the additional benefits they provide to the society as a whole. These include enabling functioning of critical facilities and avoidance of costs associated with outages, and also availability and provision of critical services to the society at large during outages.

The associated costs and social benefits of resilient distributed energy resources requires consideration of additional benefit components that would not easily be quantified in terms of value or necessarily be monetized for the benefits of the distributed energy owner/operator.
GE has been a long-time advocate of moving to smaller, decentralized energy systems. This is due, in part, to GE’s leadership in developing new and more efficient distributed energy technologies. Today, GE provides the full range of distributed energy products and services to meet this global megatrend head on. For example, our microgrid solution is a field-proven, modular and comprehensive offering that integrates primary equipment, intelligent controls and communications, with advanced visualization and supervisory control software to monitor, track, and forecast load and generation resources within the distributed power network. Each GE solution is tailored to the application and the customer’s primary objectives. Indeed, we are globally recognized for designing, delivering and servicing customized microgrid solutions for diverse applications. GE is able to offer a comprehensive solution including feasibility studies and network analysis, project management and design, primary and secondary equipment, controls and advanced visualization tools.

As a global company serving over 180 countries, we see ourselves as the world’s electricity company. And 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, factories, businesses, and homes everywhere. Our focus will remain on being a world energy innovation leader by providing technology, solutions, and services across the entire electricity value chain from the point of generation to final consumption. At GE, we are honored and humbled to be part of the emerging 21st century global power system; and we believe that the future has just begun and the best is yet to come.
REFERENCES


