Utility of the future – a Nokia Bell Labs perspective

White paper

Pervasive, wide-scale deployment of distributed generation and storage is a major disruptive force that will shape the electric power utility of the future. We provide a view into the emerging, radical changes in utility functions and business models, and the changes in utility communications networks that will be needed to support them. Significant amounts of power will be generated at consumer premises and at stand-alone distributed generation locations leading to the emergence of neighborhood and community energy exchanges. We formalize a retail energy market architecture that will support real-time energy transactions using blockchains to facilitate their execution. Widespread automation, use of data analytics to support new utility applications, and use of augmented intelligence systems by field personnel will transform utility operations. Utility communication networks will undergo transformative changes through the deployment of new devices and the adoption of virtualization, edge clouds, and network slicing. We characterize how the changes in utility applications, such as demand response, distribution system synchrophasors, and utility workforce operations will be addressed with the evolution of digital platform and the future utility communications network architecture. Finally, we include a business model for the utility of the future.

Contents

1 Introduction

To envision the electric grid of the future, it is helpful to look at the forces that have shaped the electric grid to date and envision how changes in the underlying economics and capabilities of grid technologies will shape its future.

While the fundamentals of delivering electricity to consumers have remained largely unchanged since the electric power grid emerged toward the end of the 19th century, improvements in the capabilities and economics of solar generation and battery storage technologies will drive extensive deployment of distributed generation and storage. Extensive deployment of Distributed Generation (DG)[1] will not only change the power grid, but also will change how electric power is generated, delivered and consumed. Arguably, these changes will happen at rates far greater than any changes in grid technology that have been observed over the lifetime of the electric grid. As a result, the adoption of technology and the emergence of new business models will happen far faster than has been seen in the past.

In light of this on-going technological change, we envision that in the electric grid of the future:

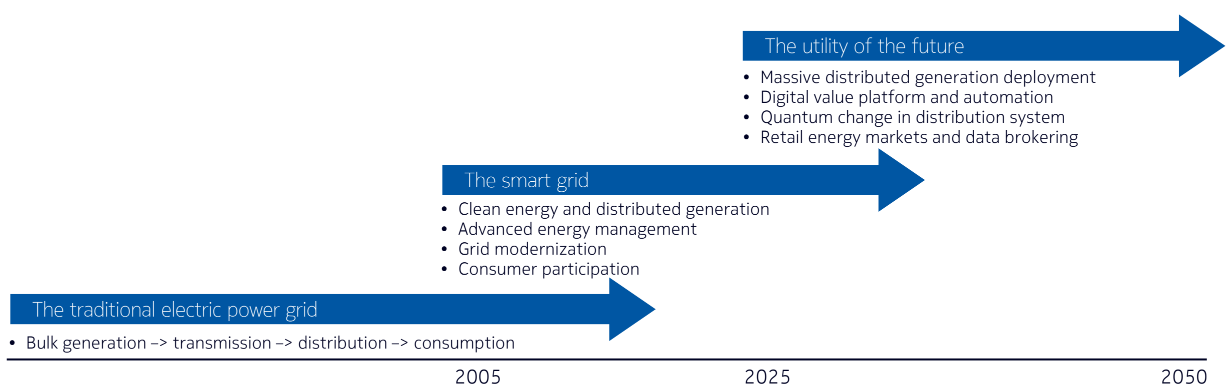
1. Over 80% of power generation will be derived from clean energy sources. Further, power generation and storage will be distributed throughout the grid where it will be most efficiently generated, distributed and consumed.
2. Adoption of digital value platforms – software systems that manage and control the generation, distribution, and consumption of energy and the operation of the electric grid – combined with advances in communication network architecture and technologies will result in orders of magnitude increase in grid operations efficiencies
3. Pervasive sensing of the electric grid, distributed control of distribution generation and consumption, and the use of augmented intelligence to support grid operations and control will result in significant reductions in power outages.

These changes will drive adoption of new Information and Communication Technologies to support both the adoption of new grid technologies and the emergence of new business models.

1.1 Electric power grid and utility evolution

Figure 1 shows the power grid and utility evolution from late 19th century to the middle of the 21st century.

Figure 1. Power grid: past, present, and future



1 DG is also called Distributed Energy Resource (DER).

In the traditional grid, electricity flows from bulk power plants through high voltage transmission lines, and through medium voltage distribution lines (feeder) before being delivered to consumers. Electricity flow is unidirectional. In many countries, transmission and/or distribution utilities[2] are often regulated, while generation is unregulated. Utilities may be vertically integrated, with generation, transmission, and distribution owned by the same company.

1.2 Smart grid evolution

Smart grid evolution is characterized by one or more of the four characteristics:

1. Proliferation of renewable energy, particularly clean energy. While, bulk clean energy plants are emerging, it is the growth in clean energy DG that is primarily driving smart grid evolution.
2. Efficient energy management using wide deployment of Advanced Metering Infrastructure (AMI) and Distributed Automation (DA). Real-time Demand Response (DR) is being implemented with Automated Demand Response (ADR) programs. Support of these energy management functions requires communication with devices deployed throughout the distribution grid and in homes and enterprises.
3. Smart grid evolution also provided an impetus for grid modernization. In addition to improvements to physical infrastructure, deployment of synchrophasors, DA, Dynamic Line Rating (DLR), and Flexible Alternating Current Transmission System (FACTS) are facilitating modernization of the power grid.
4. Active consumer participation in energy management is a direct consequence of smart grid evolution. Some of the consumer activities include subscribing to utility consumer portals, AMI, ADR programs, direct load control with automation of home appliances by third parties (including utilities), and clean energy deployment at residences and businesses.

For a more detailed treatment of smart grid, smart grid applications, and smart grid communication networks see [1].

Smart grid has provided a much-needed boost to the electric power industry and its aging infrastructure. Smart grid also provides benefits for consumers, and for the society in general (e.g., reduction in greenhouse gases). Adoption of smart grid technology will in turn drive more rapid changes in the grid technology and business models.

1.3 Disruptions defining the utility of the future

Grid transformation through the adoption of smart grid technologies has been a slow evolution in many parts of the world. Ever-expanding and rapid DG deployment, however, will be disruptive – fundamentally changing the way a utility functions and how electric power is generated and distributed to consumers. Some of the main characteristics of this utility of the future are:

1. A significant amount electric power will be generated at consumer locations and at stand-alone DG locations – all connected directly to the distribution grid. Steadily decreasing prices for electric power storage (e.g., batteries) will further accelerate DG deployment. Virtual power plants (VPP) - where DG deployment in a community with appropriate electric storage and automation applications collectively behaves like a “visualized” power plant generating electricity for the community - are already becoming a reality.

2 A distribution utility may be called distribution network, distribution system or distribution network operator.

2. Energy exchange within a neighborhood or community will become prevalent with consumers selling excess energy to one another. Facilitating such a peer-to-peer energy exchange will be a significant function of the future utility in addition to delivering power received from bulk power plants through transmission systems as necessary. These new energy exchanges will probably even be independent of current energy trading systems.
3. Retail energy markets will emerge, develop, and mature to support real-time energy transactions [1].
4. Digital value platforms will become an integral part of the utility with widespread automation through use of data analytics in new utility applications, artificial intelligence, and augmented reality systems in utility operations. Advances in communication network architecture and technologies ([2]) will facilitate digital value creation in addition to transforming communication networks in the utility of the future.

The magnitude of changes in different components (or aspects) of the electric power grid and the utility functions is summarized in Figure 2.

Figure 2. Magnitude of changes in components of electric power grid and utility functions

Generation of the future	Total disruption with massive distributed generation
Transmission of the future	Evolutionary changes to transmission utilities
Distribution of the future	A complete transformation of distribution utilities
(Energy) markets of the future	Rise of the retail energy market, new business models
Consumer of the future	(Automated) participation in energy markets
Utility operations of the future	Proliferation of new applications, automation++
Utility ICT of the future	Digital value creation, data-driven automation

2 Generation of the future

Traditionally, bulk energy sources based on fossil fuels (coal, oil, natural gas), nuclear, and large hydro have been the main sources of electricity. Each power plant typically has a capacity of hundreds of megawatts (MW) and connects to the transmission lines to carry electricity to distribution grid. Lately, renewable energy sources such as solar and windfarms are increasingly being deployed as bulk energy sources[3]. In addition to DG deployment at consumer locations, standalone DG deployments are also deployed and connected to the distribution grid. These distributed DG sources (which will mostly consist of clean energy sources) will define the utility of the future.

2.1 Generation sources of the future

A few observations on current trends generation trends that are relevant to the utility of the future:

1. Almost 25% of total world-wide electricity generation at the end of 2016 was produced by renewable sources [3]. A large portion of that (~17%) was attributable to large hydro power with solar, wind and other renewable sources contributing to the remainder.

3 For example, 648 MW photovoltaic (PV) power plant solar in Kamuthi, India 1,000 MW Concentrated Solar Power (CSP) plant in Dubai.

a. While there will not be much growth in the large hydro power in the future, contributions from other types of renewable energy sources are increasing at a very rapid rate. For example, in 2016, while the worldwide hydro power generation increased by about 4%, solar power generation increased by 25%.

2. Among the (non-hydro power) renewable energy sources, most of the new deployment is shared by wind power and photovoltaic (PV) solar power. Solar PV represented about 47% of newly installed renewable power capacity in 2016, and wind and hydropower accounted for most of the remainder.
3. A few findings from the SunShot initiative of the US Department of Energy's (DoE) Solar Energy Technology Office ([4] and [5]) are relevant to the grid of the future:
    a. Solar has made great strides in the United States. In early 2011, solar power comprised less than 0.1% of the US electricity supply with an installed capacity of just 3 gigawatts. As of 2017, solar now supplied more than 1% of US electricity demand with an installed capacity of more than 47 gigawatts.
    b. In 2017, the Levelized Cost of Energy (LCOE) per kilowatt-hour (kWh) of electricity reached 6 cents per kWh for utility solar installations. Achieving an LCOE of US $0.03 (3 cents) per kWh – the current cost of generating electricity from traditional sources – is expected by year 2030 for a utility with similar cost reductions for residential and business solar deployments.
    c. Solar energy (both PV and Concentrated Solar Power - CSP) with energy installations in the US from solar may be as much as 14% of total consumption in 2030 increasing to about 27% in 2050.
    d. If the energy storage costs were to decrease rapidly to about US $100/kWh for 8-hour battery, by 2050, solar energy may be as much as 50% of the total US electricity generation[4].

The cost of energy generated from distributed solar sources is dropping substantially and will soon be cost-competitive with traditional bulk energy generation. Meanwhile, the cost of battery-based distributed storage is dropping rapidly due to large-scale investment in battery technology in the automotive and other adjacent industries. As a result of these trends, energy generation in the future will rely heavily on pervasive, wide-scale deployment of distributed, solar-based generation and storage.

2.2 Energy storage

Cost-effective storage is critical for the proliferation of distributed generation. In addition to the storage associated and collocated with DG installation, standalone distributed storage can help stabilize the power grid and facilitate demand response. There is a great interest in increasing efficiencies and reducing costs of existing storage technologies (e.g. batteries), as well as CAES (Compressed Air Energy Storage) and in inventing new storage technologies (e.g., electrochemical capacitors and synthetic natural gas) [6].

A few observations on electric storage trends that are relevant to the utility of the future:

1. While other types of storage technologies may be in use, batteries (from Lithium-ion to lead acid to flow batteries and other battery technologies) are the most prevalent storage currently used in DG deployment.
2. Battery prices are falling and are expected to fall further in future. For example, electric vehicle battery pack prices have fallen 77% in the last 6 years to US $227 per kWh and expected to fall to US $100 per kWh in the future [7]. A theoretical model [8] predicts that the price may fall to US $80 per kWh.

4 In fact, if all renewables are included, utilities like Xcel Energy are predicting well over half its electricity will come from renewable sources by the mid-2020s. See https://www.nytimes.com/2018/02/06/opinion/utility-embracing-wind-solar.html

3. Newer battery technologies are increasing battery efficiencies; battery energy density is increasing about 5%-8% per year.
4. In addition to batteries connected to DG sources for power stability, standalone batteries are used during power outages. Utilities are teaming with battery manufacturers to offer customer battery backup solutions. (Example: Tesla and Green Mountain Power [9], Tesla and South Australia to provide energy to the city residents during power outages [10]).
5. With the proliferation of electric vehicles, vehicle batteries can provide readily available connectivity to the grid – in addition to charging batteries, discharge into the grid to act as a DG source.

The economics of battery-based storage are improving rapidly. As a result of these trends, battery storage will be deployed at homes and businesses. Arrays of batteries will be deployed throughout the distribution grid, further improving the economics of distributed storage and generation.

2.3 Virtual power plants

In the future, utilities will need to support pervasive Virtual Power Plants (VPPs). A VPP is a collection of consumer-located DG such as solar photovoltaic (PV) and battery systems connected to the grid and working together to generate, store and feed energy back into the grid. A VPP, even if distributed, acts like a power plant supplying electricity to utility customers. Excess energy from individual DG systems (after being used locally) is delivered to the grid. The amount of energy delivered to the grid is controlled by the utility. VPPs are already emerging [11]. As an example, a VPP based on local PV deployment and Tesla batteries will support a community of 50,000 customers in South Australia [12].

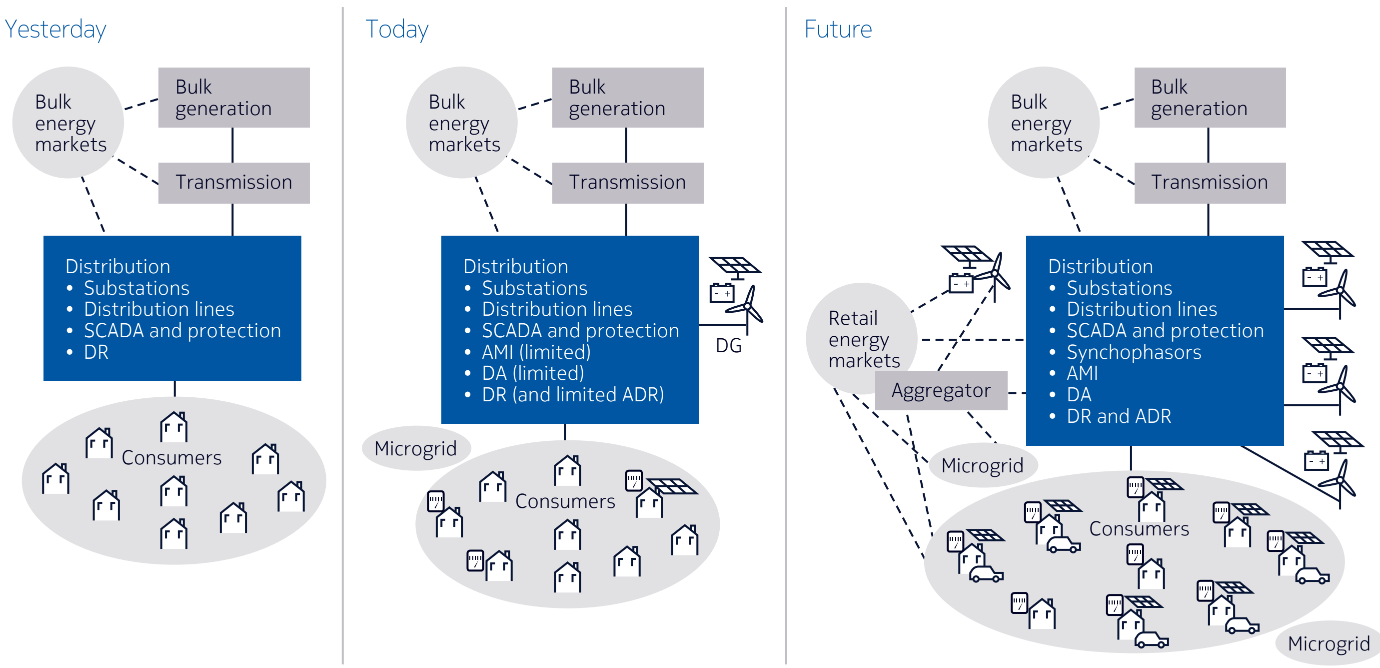
As the economics of distributed generation and storage continue to improve, VPPs will become wide-spread. Deployment of VPPs requires tight coupling of distributed generation, distributed storage, consumption, and the distribution grid. To ensure power quality and grid stability, additional sensors (e.g., synchrophasors) and controllers will need to be deployed and managed throughout the distribution grid. These trends will result in significant changes to distribution grids throughout the world. Control and management of VPPs will require pervasive, real-time communications throughout the distribution grid. Large volumes of data will need to be collected, analyzed, and shared among the many new applications that will emerge. Distribution service operators will need to ensure the increased level of variability in supply and demand does not cause grid instability. Further, as much of the legacy equipment deployed in a distribution grid was engineered for unidirectional energy flow, distribution service operators will need to deploy additional measurement and control devices. Deployment of these devices will allow distribution service operators to “sweat” their legacy assets – ensuring that the bi-directional flow of energy stays within the engineering tolerances of their legacy equipment.

3 Distribution utility of the future

Disruption caused by massive DG deployment will have the greatest impact on existing distribution utilities[5]. Not only will there be changes in the way electricity is generated and delivered, but also there will be changes in the way the distribution utility manages the grid, procures electricity, and along with the consumers becomes a participant in energy management. – becoming a Distribution Service Operator (DSO) [13]. Figure 3 depicts the evolution of distribution utilities.

5 Distribution utilities may be independent entities, or parts of transmission and distribution utilities, or parts of vertically integrated utilities

Figure 3. Distribution utility through years



3.1 Traditional distribution utility

The distribution system is comprised of (distribution or secondary) substations connected by distribution lines. Distribution system applications include Supervisory Control and Data Acquisition (SCADA) systems monitoring and controlling Remote Terminal units (RTUs) or Intelligent Electronic Devices (IEDs) at substations and protection systems monitoring and correcting faults. Most of the Demand Response (DR) methods are based on short-term energy markets with voltage control (blackouts or brownouts) being the near-real-time DR tool. For detailed description of DR methods – traditional, emerging, and future – see [1] and [8].

3.2 Smart grid and distribution utilities

Smart grid evolution has brought many changes to distribution utilities [1]. (See Figure 3.) Some of these changes include:

1. Connection of DG to the distribution grid – both at consumer locations and stand-alone DG deployment. Distributed Storage (DS) and Electric Vehicles (EVs) are also connecting to the distribution grid.
2. In addition to modernizing the SCADA and protection applications, new applications are introduced: monitoring and protection of DG connectivity, DA and AMI.
3. More efficient and near-real-time DR is now possible (including Automated DR – ADR) with emerging dynamic pricing and direct control of consumer appliances.
4. These and other smart grid initiatives have helped launch many new and innovative distribution management systems making Volt, VAR, Watt Control (VVWC), Outage Management System (OMS), DR, and many other utility operations functions more efficient and responsive. Energy management and distribution grid reliability and performance are improving at a very high rate.

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3.3 Distribution utility of the future

Key characteristics of consequences of the disruption caused by massive DG deployment (see Figure 3) are:

1. Exchange of electric energy within a neighborhood will become commonplace with energy transactions between neighbors (possibly informal peer-to-peer applications). The utility will be required to affect the corresponding energy transfer through the grid. Electricity bills (and the corresponding metering) will be more complex and will itemize the energy received by a customer from the utility (including indirectly from the bulk supplier), and from neighbor(s) as well as energy sold by the customer to the utility as well as to the grid. There may be different rate structures that the utility may be required to maintain depending on time of the day, weather conditions, DG source and location, etc. AMI deployment will be ubiquitous.
2. Retail Energy markets (REMs) will emerge capable of processing millions of energy transactions as DG proliferates and retail energy sales are routine and frequent. For a more detailed discussion of REM see [1] and [16].
3. Utilities will need to support large-scale deployment of VPPs.
4. Monitoring and protection of all DG connections to the grid will be required. Further, synchrophasors will be deployed at higher densities along distribution asset locations to more accurately and more granularly monitor and control power quality. These processes will need to be automated since grid state estimation of the higher number of distribution assets will be too complex for today's methods.
5. In contrast to the traditional DR methods already in use, the utility will institute many newer, automated methods for DR programs with (automated) consumer partnership for energy management, energy conservation, peak power reduction, and guarding against outages. In the utility of the future, near-real-time DR will be commonplace with a significant consumer participation. A closed loop continuous feedback system is necessary to enable this level of participation that will include subscription to dynamic pricing and utility control of appliances. With the advent of Home Energy Management Systems (HEMS), ADR will be possible with communication between HEMSs and utility DR systems. With REM, utilities will be able to draw upon DG energy sources for DR in addition to traditional day-ahead and sport bulk energy providers.
6. The utility communication network will undergo transformative changes with virtualization and new networking technologies. These and other related topics are covered in detail in Section 4.

The three most impactful characteristics of the utility of the future listed in the beginning of this paper can only be achieved through digital value creation with use of data analytics, machine learning followed by artificial intelligence, and augmented reality in automating most utility operations aided by the communication network of the utility of the future. These topics will be covered in Section 5.

4 Communication networks in the utility of the future

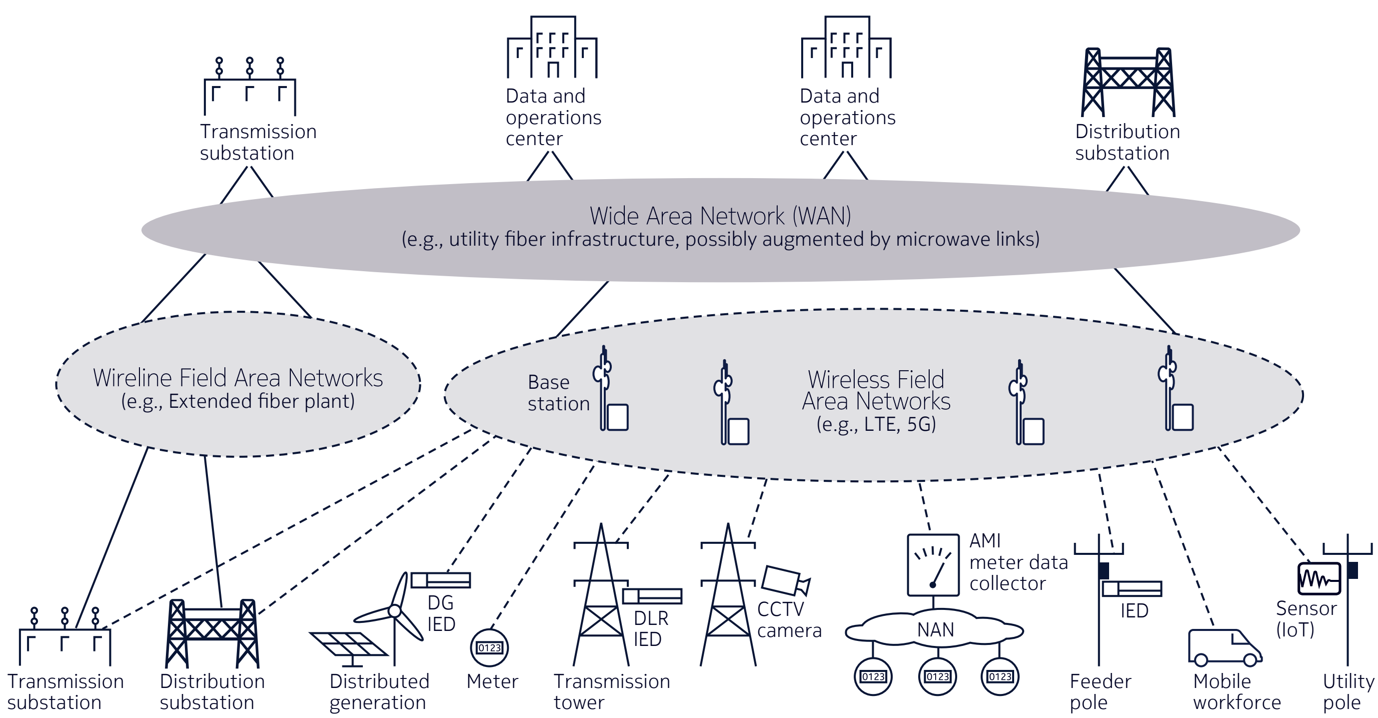
Utility communication networks will evolve from supporting the smart grid to incorporating virtualization and other groundbreaking networking developments into the communication network for the utility of the future.

4.1 Smart grid communication network

Traditionally, in a utility grid, communication networks were required for two main applications: SCADA and protection. In most cases, separate network topologies were deployed to support each of these applications. With the advent of smart grid evolution, many new applications (e.g. DA, DG connectivity, synchrophasors, AMI, CCTV for physical security) required communication between application endpoints.

As utilities began to introduce one or more of the new applications for smart grid, often, a new network and/or new network technology was deployed to support each of these applications. Communication networks will be an essential and integral part of smart grid [1]. The legacy practice of deploying purpose-built disparate networks is not sustainable. A smart grid communication network architecture framework that supports all smart grid and utility application is necessary. The network architecture for the smart grid is shown in Figure 4.

Figure 4. Smart grid communication network architecture framework



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For details of the architecture, refer to [1]. Here we make a few, summary observations:

1. This is a core-edge architecture with some of the larger utility establishments connecting directly to the core – called the Wide Area Network (WAN). Typically, the Data and Operations Center locations and some of the substations connect to WAN, based on their proximity to the WAN. In many cases, the WAN leverages utility fiber infrastructure (embedded in optical ground wire or fiber deployed over utility rights of way), augmented by point-to-point microwave links, as needed.
2. All remote utility endpoints connect over access networks called Field Area Networks (FANs). We expect that in some cases, FAN connectivity will be provided by extended utility fiber infrastructure; but in most cases – owing to economic consideration – a single broadband wireless network such the Long-Term Evolution (LTE) will provide such connectivity. (LTE may migrate to 5G networks in the future.)
3. Note that endpoint devices such as meters and Intelligent Electrical Devices (IEDs) and grid sensors of various applications that have been traditional machine-to-machine (M2M) applications will be considered Industrial Internet of Things (IIoT) devices going forward. Additionally, IIoT devices will be deployed, resulting in a 10x-100x increase in the number of devices that must be managed and controlled. These new devices will be installed on utility, enterprise and consumer assets. The devices will be installed by utilities as well as other organizations for a variety of new purposes (to support smart city applications, for example).
4. The networks types referenced in figure 4 (WAN, FAN and various LANs), will require appropriate secure, reliable, standards-based technologies to work in harmony to create a closed loop communication system as discussed earlier.

4.2 Communication networks in the utility of the future

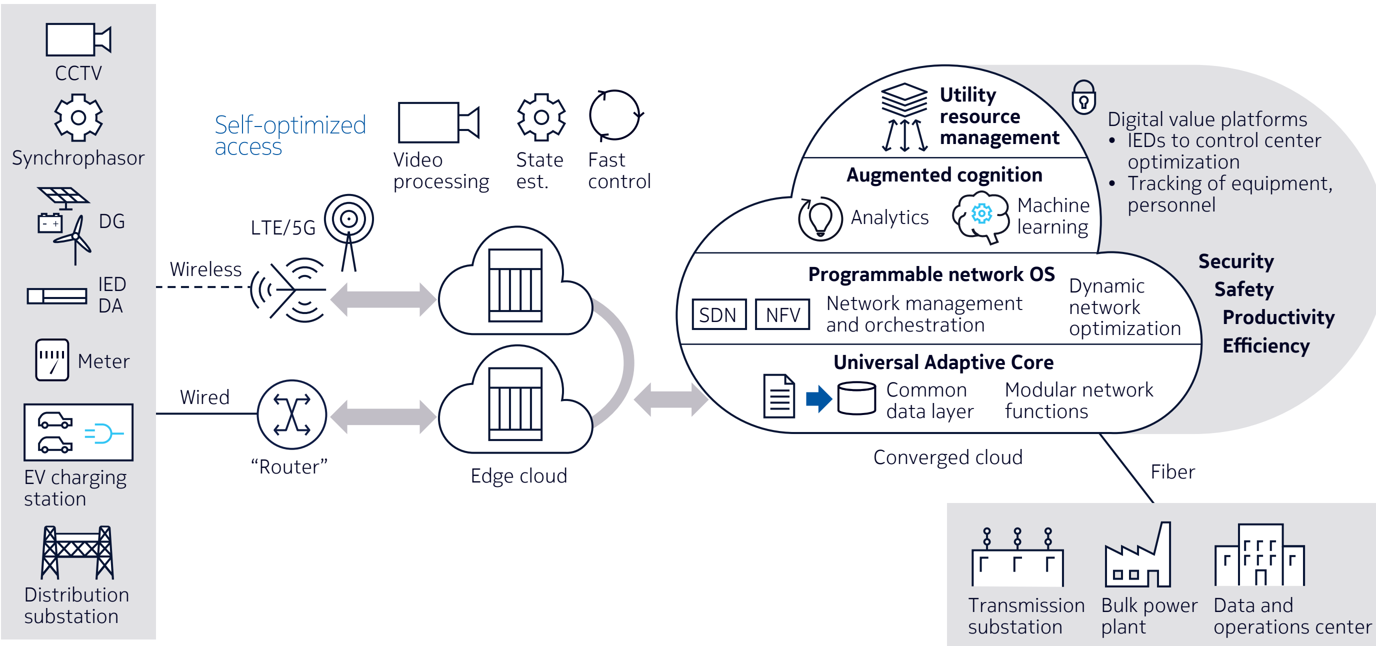
Utility communication networks will undergo fundamental changes to support the trends and disruptions outlined above. The rate of change for communications technologies in general has increased. These trends will impact how utilities utilize communications technologies for their own purposes. Not only will the networks of tomorrow support a very large number of IoT devices (in addition to devices carried by utility personnel), there will be two orders or magnitude increase in required bandwidth, reduced network delays, and decreasing networking costs. Virtualization is being utilized beyond the data and control centers driving cloud technology in the network with the advent of Software-Defined Network (SDN) and Network Functions Virtualization (NFV). Virtualization will extend to the edges of the network with edge clouds – where delay-sensitive processing and control functions will be processed. Advances in networks and expected groundbreaking changes are described in [2].

It is worth noting that in the past many communication technologies could be deployed over life cycles of similar duration to the life cycles of electrical assets. This allowed communications costs to be depreciated over large capital project life cycles. One consequence of the acceleration of technology innovation is that it will drive industries that use the communications to have shorter or even continuous refresh cycles as they utilize communications more strategically. Changes in asset management processes and accounting practices will therefore need to be updated to reflect this trend.

4.2.1 Virtualization

The network transformation vision includes core and access networks, wireless and wireline networks, communication and information, IoT networks, home networks, and finally, network operations. The utility communication network for the utility of the future will undergo such transformation. A schematic of the cloud-integrated future utility network architecture is shown in Figure 5.

Figure 5. Schematic future utility communication network architecture



The future utility network is a core-edge architecture as was the case for the smart grid (Figure 4). Further, connectivity will be based on fewer networking technologies: such as fiber and 4G wireless (e.g., followed by 5G) but in tighter coordination with virtualization tools. It follows that there will be significant changes in the way network connectivity is managed and traffic flows are handled: network elements together with the network operations and control systems will support virtualization with SDN and NFV in a dynamically optimized network. Networking applications will be executed at the SDN controller and NFV systems in the virtualized Data and Operations Center (DOC). The main advantage of virtualization is that instead of the legacy practice of building a network around the utility application requirements the network will be programmed with the application's requirements so that it is aware of the needs of the upper level applications before a new network service is even created. This means the network can react to changes in requirements in real time rather than through a series of layered changes applied manually. Advances in future programmable network operating systems have promises of making networks more efficient and automated; for example, network bandwidth allocation and routing can be adjusted quickly in response to changing application requirements (new DG assets inserted) or in network state change (storm outage) or situational criteria (nightly backups). Seamless end-to-end network security will be implemented rather than only network component-specific security implementations.

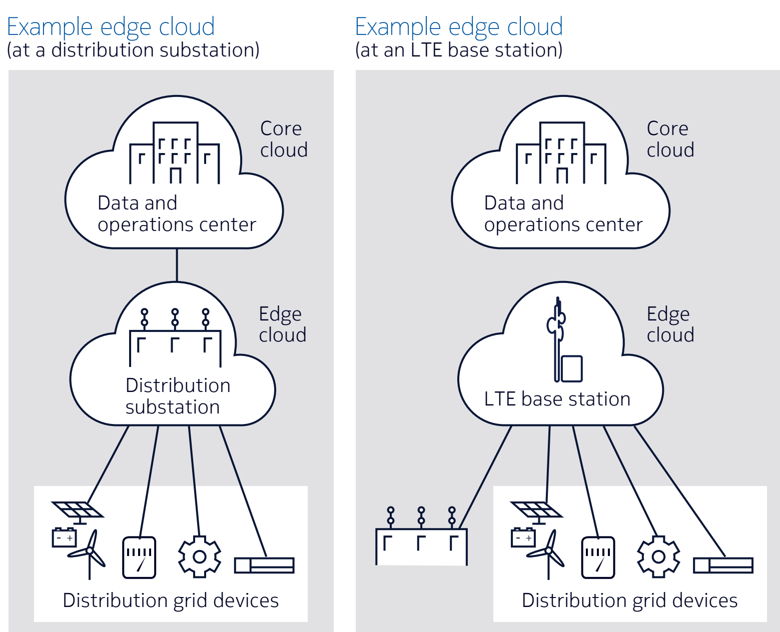
4.2.2 Edge cloud

While some applications will continue to be centralized and may use (centrally stored) data collected from network endpoints, virtualization affords efficient distribution of applications to the edge of the network. Processing of data collected at end devices can be accomplished at the edge of the network (such as at a substation) for some applications instead of centrally at a DOC. Virtualization will help achieve such processing on general-purpose hardware, or on a card in a substation network element such as a router. Implementing edge cloud (sometimes called distributed intelligence) has many advantages. Often local decisions depend only on local data; there is no need for such data to be transmitted to a DOC. An example is video analytics for general theft monitoring or situation crew safety operations. Video analytics can be performed locally at a substation using locally collected CCTV data from cameras at the substation and at transmission/distribution lines emanating from the substation. While measurement data from IEDs and RTUs may be sent to the DOC for utility-wide decision making and control for applications like VVWC and DA, the data may also be locally processed in edge clouds for local decisions and control. In addition, response time requirements for grid control, teleoperation of drones and other delay-sensitive allocations will require processing to be done close to the end devices, avoiding speed of light propagation delays. Speed of light propagation delays can be substantial in large electric grids. For example, round trip transmission over fiber between a device and processing resource located 100 km away results in 1 ms of delay due to speed of light propagation. With reduced delays, decision-making will be very fast, reducing fault times and rapid automated switching decisions.

For some of the applications, central processing of measurements is not feasible. A case in point is synchrophasor deployment along distribution lines. State estimation based on synchrophasor data must be completed within only a few cycles of the AC waveform. To ensure power quality remains high as DG is deployed throughout the distribution grid, utilities will need accurate state information. Therefore, local processing of the synchrophasor data at the corresponding distribution substation is essential. Edge cloud implementation makes this possible.

For utility networks, edge cloud implementation at a substation (router) is an obvious choice. Other locations are also possible: for example, at wireless network (such as LTE) base stations as shown in Figure 6 or at a WAN point (such as a WAN router) where traffic from many remote endpoints is aggregated.

Figure 6. Edge cloud implementation: example edge cloud locations



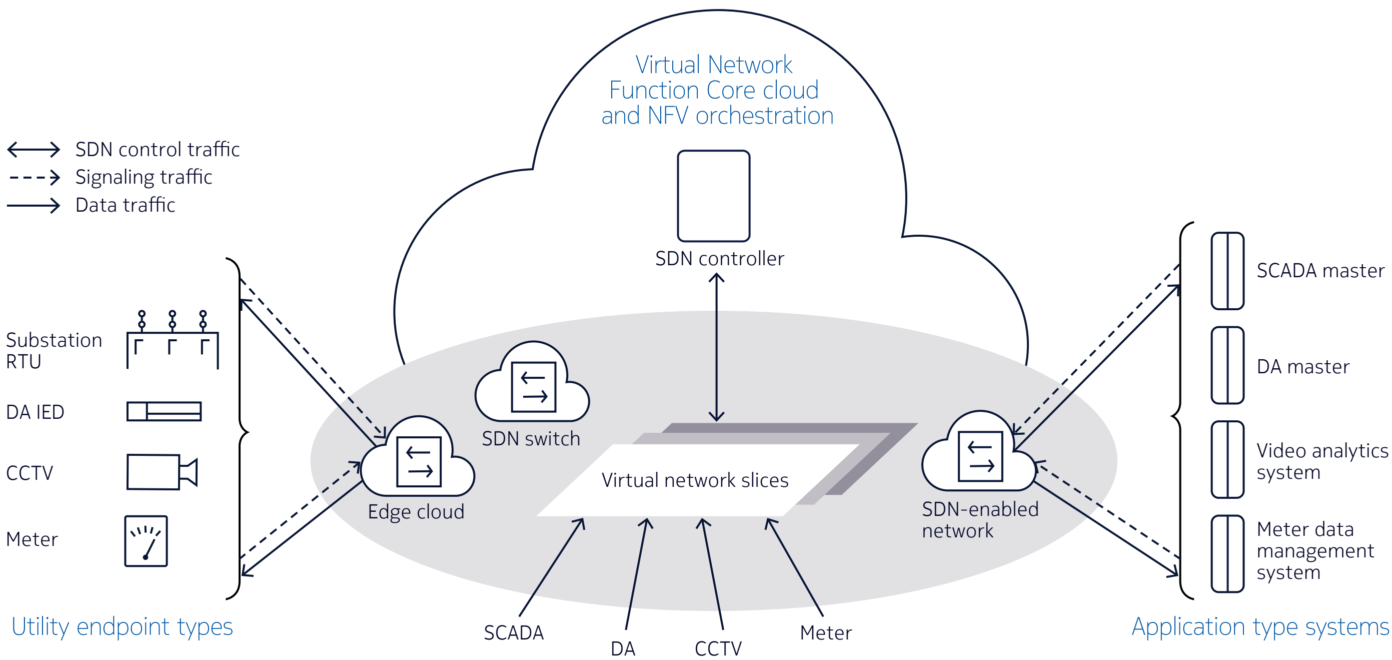
Network elements (routers, base stations, etc) and/or other host systems with virtualization capabilities are becoming increasingly available. As a result, edge clouds can be established and processing of local data and control of local devices can be implemented.

Edge clouds are one of the many benefits of virtualization that is applicable to utility networks. Virtualization is now routine in data center operations. For example, data center (including DOC) operations will be more efficient, more versatile and flexible, and with significant cost reductions.

4.2.3 Network slicing

Network slicing is a concept for running multiple logical networks as independent business operations on a common physical infrastructure [14].

Figure 7. Network slicing in utility network supporting different applications.



Virtualization with SDN and NFV helps create network slices, with each network slice created for specific purpose. For example, a slice can be used to carry traffic only for a single application or for a group of applications. In Figure 7, four network slices are shown for four different applications: substation SCADA, DA, AMI, and CCTV. Network resources can be dynamically allocated to each slice as required. Security policies corresponding to the application(s) supported by a slice can be independently administered and implemented for that network slice. Each network slice is a virtualized end-to-end network as multiple slices running in parallel on common physical network infrastructure. Network slices can also be used for areas like regulatory compliance on shared infrastructure such as isolating higher security or higher impact asset classes access from non-regulated asset access. Virtualization for a slice can be implemented at network elements such as SDN switches (shown in Figure 7) or even in other network elements such as base stations of wireless components of the utility network. In the latter case, slicing can even be extended to spectrum resources [15].

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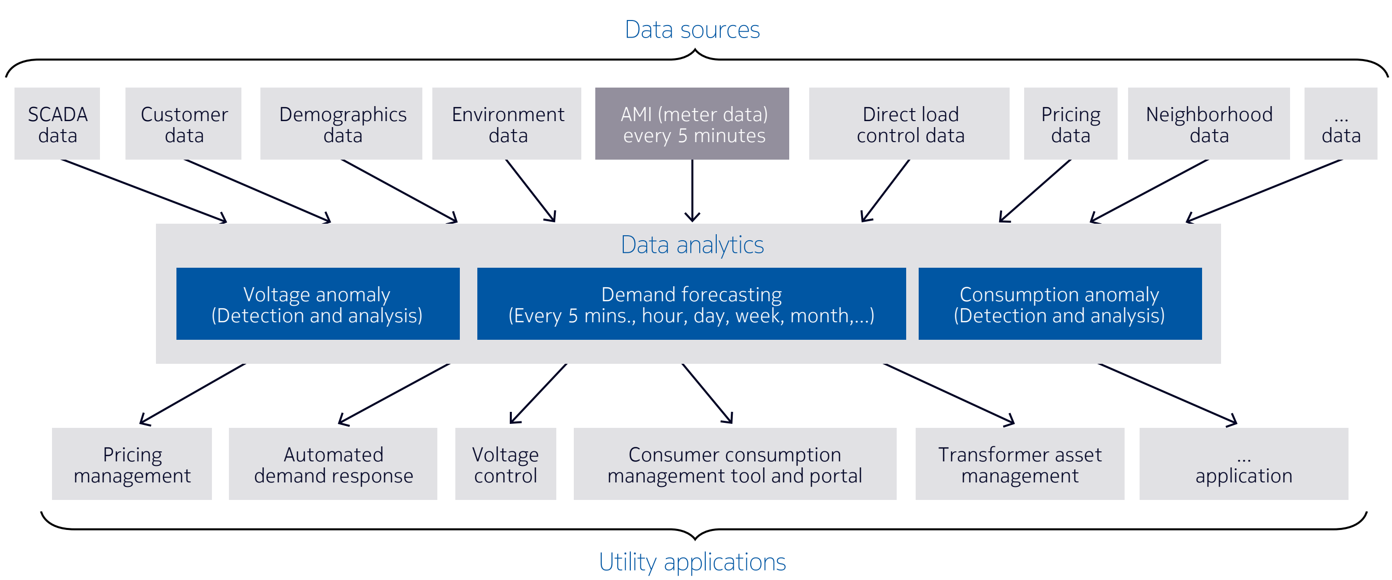
5 Digital value platforms – analytics, artificial intelligence, augmented reality

Many leading enterprises and service providers are rapidly creating digital value platform to automate their operations, provide new services, and support new business models. This is particularly critical for mission-critical services such as for electric power utilities. Operations automation is crucial for speed, significant reduction in operations errors, and other efficiencies. Three important components of digital value platform are discussed in this section; data analytics, artificial intelligence / machine learning (AI/ML), and augmented reality (AR). (Additionally, blockchain will be at the heart of the transaction management in Retail Energy Markets.)

5.1 Data analytics

Ever-increasing utility applications (e.g., AMI, DA, synchrophasors) and their endpoints and continuous monitoring of utility devices requiring drastically reduced measurement intervals have tremendously increased the amount of data that a utility will collect. For example, a utility serving 3 million customers with each meter reporting every 5 minutes with about 100 bytes of measurements will collect about 32 trillion bytes of data each year. In addition to the obvious use of such data for intended focused application, there is a wealth of value in the data that can be extracted using analytics to support operational, business, consumer, and environmental applications of the utility. We illustrate this by means of an example in Figure 8. In this example, analytics of smart meter data collected every 5 minutes and other ancillary data help support many utility applications including pricing for consumers, demand response, consumer portal, asset management, and other applications and services.

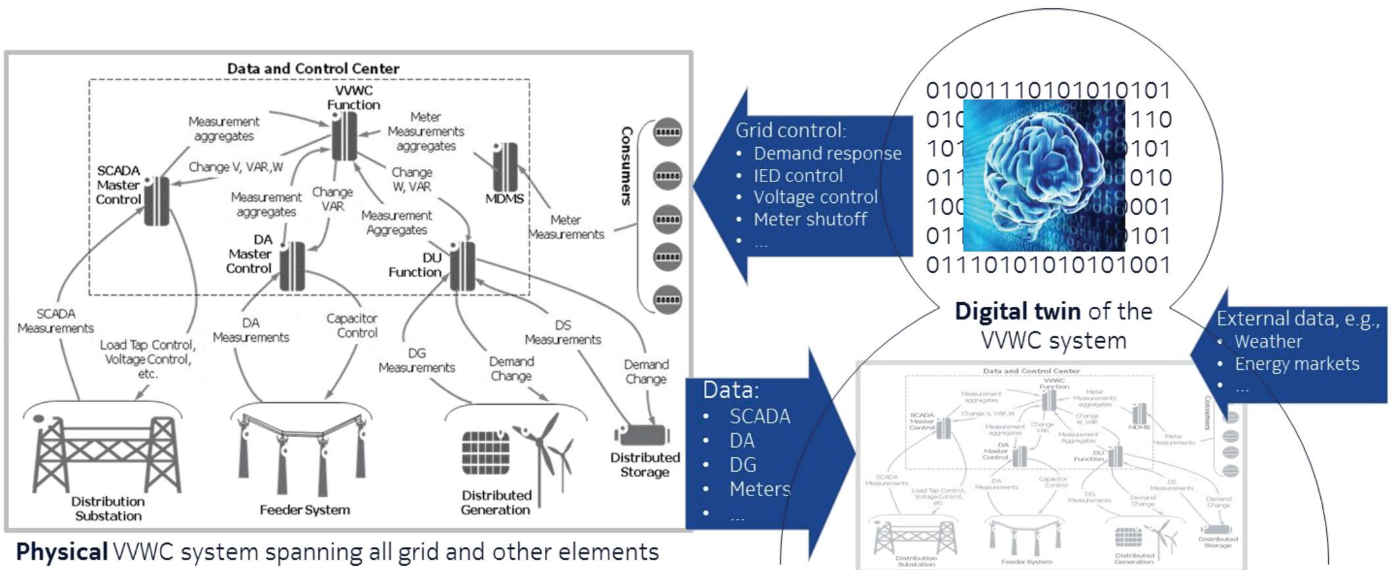
Figure 8. Smart meter data analytics and example utility applications supported



5.2 Artificial Intelligence (Machine Learning)

Machine Learning begins as assisting a human to correlate and find patterns faster to utilize data from multiple sources beyond what the human could process alone. AI (or AI/ML) is a function of a machine (such as a utility device or a function or combination thereof) which mimics a human's cognitive functions to make decisions on its own. As an example of how AI/ML is useful in the context of the utility of the future, consider a complex VVWC system that must make multiple decisions including those related to voltage regulations, reactive power elimination/reduction, and/or peak power management. The decision-making is based on a large amount of data collected from SCADA, DA, AMI, and other applications. The AI system supporting the VVWC functions will receive all the data usually delivered to the VVWC "machine" and operate on the model (digital twin) of the VVWC machine to generate the control signals that are sent to the appropriate devices and/or operators for required action (Figure 9).

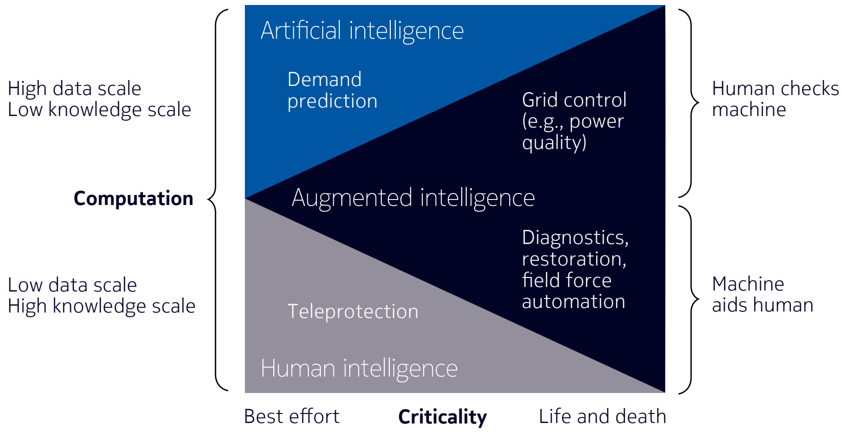
Figure 9. VVWC using Digital Twin



Source: Budka, Deshpande, Thottan, "Communication Networks for SMart Grids: Making Smart Grid Real", Springer 2014

Real-time AI systems can process a large amount of data in a very short period of time (at millisecond timescales and shorter) as compared with Human Intelligence (HI) systems that are based on humans operating on a small amount of data over a longer period of time (see Figure 10).

Figure 10. Augmented Intelligence (AugI)[6]



There are cases when decisions made by AI systems alone may not be satisfactory, resulting in the need for human intervention. In those cases, an Augmented Intelligence (AugI) system may be useful, where the AI system presents available options quickly, and a human operation may decide on the right option to implement. A few examples of utility operations functions are mapped onto the AI, HI, AugI plane (Figure 10). Consider the example power quality maintenance in a distribution grid. Before DG deployment became commonplace, substation measurements every few seconds were enough for a human operator (possibly using simple tools) to maintain power quality in the distributed grid. With a large number of DG sources connecting into the distribution grid, power quality suffers and must be continuously monitored and corrected. HI systems will certainly be very coarse and ineffective in the presence of DG. Utilities are deploying synchrophasors in the distribution grid to make voltage phasor measurements 50/60 times a second and computing the state of the grid continuously based on these measurements. These computations can be automatically fed into an AI system that detects erosion in power quality and automatically corrects it. However, such continuous remedial systems can be prone to overcorrection of power quality and may lead to transients. An AugI system may be developed where human intervention is possible to decide on sending of the corrective signals to the grid devices.

5.3 Augmented reality (AR)

AR provides a view of a physical, real-world environment to utility operators and field force whose elements are "augmented" by computer-generated multimedia inputs. Such multimedia inputs like sound, video, or graphics can also be extracted from sensor data. In addition to computer screens and hand-held devices, the AR user can get a real-life experience from "wearables" such as AR glasses.

In the utility of the future, AR will help with increased safety, reduced time, optimized operations, and improved quality. Some of the direct applications for use of AR in utility operations are:

1. Troubleshooting
2. Remote assistance
3. Asset inspection, visualization of hidden assets (e.g., underground power lines)
4. Education and training
5. Simulations

6 We gratefully acknowledge our Nokia Bell Labs colleagues Chris Jones, Marcus Weldon, and Chris White for developing this conceptual view of the roles played by Artificial Intelligence, Augmented Intelligence and Human Intelligence in industrial automation systems.

6 Business models for the utility of the future

New business models will be developed in the utility of the future. New business models will be required for energy rating and customer billing, utility cost structure and revenue streams, energy markets and participation therein, and customer-supplier relationships. Regulatory changes are also expected with paradigm changes in energy suppliers.

That will add complexity to development of new business models. In fact, the definition of a distribution utility itself will change.

Here we present a simple new business model pertaining to billing of a utility customer connected to the grid.

Current business model:

We assume that a customer connected to the distribution utility receives all its energy needs from a single bulk energy supplier. In the case of a regulated utility, the distribution utility delivers to its customers electricity from multiple bulk suppliers including possibly its own unregulated holding company. In the case of a vertically integrated utility, the utility itself is the supplier of electricity.

For simplicity of this business model, we assume that the customer only consumes energy; i.e., it does not own a DG source supplying electricity to the utility. The customer monthly bill has two components:

$$\text{Monthly bill}^{7} = f(\text{consumption}) + g_B(\text{consumption}),$$

Where, consumption is the monthly consumption (in kWh) of the customer. The function f denotes utility charges for connecting and servicing the customer. Function g_B denotes the supply charges for electricity consumed (collected by the utility).

Note that the functions f and g_B may be different for different classes of customers.

New business model:

In the new business model, a customer may own a DG connected to the grid or their community may own a neighborhood DG asset or both. Also, there may be a stand-alone retail DG (non-utility owned) that supplies energy to consumers in the immediate distribution grid or part of a VPP grid. . In this case, the customer bill may have up to five components:

$$\text{Monthly bill} = f_1(\text{consumption}_B+\text{consumption}_{DGR}) + f_2(\text{supply}_{DGS})$$

$$+ g_B(\text{consumption}_B) + g_{DG}(\text{consumption}_{DGR})$$

$$- h_{DG}(\text{supply}_{DGS})$$

Where, consumption_B and consumption_{DGR}, respectively are monthly consumption of energy received by this customer from a bulk supplier(s) and received from a DG supplier(s) based on REM transactions. supply_{DGS} is the energy sent to the grid by the customer DG (if any). Functions f_1 and f_2 denote utility charge for supporting the customer connected to the grid – both for receiving electricity and sending electricity from its DG, if appropriate. If there are multiple bulk and/or DG suppliers for this customer, there will be multiple such entries in the bill. Functions g_B and g_{DGR} are the supply charges for electricity consumed by the customer (collected by the utility for respective bulk and DG suppliers, based on REM transactions. Once again, if there are multiple bulk and/or DG suppliers for this customers, there will be multiple such entries in the bill. Functions g_B and g_{DGR} may be different for different suppliers.

7 f, g, h, and all the other billing related functions are monotonically non-decreasing, but not necessarily linear

Finally, the utility pays this customer for the electricity sent to the grid by the customer (if any since it could be stored locally or sold peer-to-peer), denoted by function h_{DG}. Note the negative sign in front of the fifth term. Thus, it is possible that the utility pays a customer who delivers a large amount of electricity compared with its own consumption or even groups them into VPP with shared profits based on total participation.

7 Concluding remarks

Pervasive, wide-scale deployment of new and economical electrical technologies like distributed generation and storage is a major disruptive force that will shape the electric power utility of the future. In this paper we have provided a view into the changes in utility functions and business models and the changes in utility communication networks and operations that will be needed to support them. Future generation will be comprised of clean energy sources replacing most of the bulk generation. Falling energy storage (e.g. battery) prices and their increasing efficiency will accelerate DG deployment. Of the various utility components and functions, distribution utilities will undergo transformative changes with major changes in utility applications, emergence of REMs, and new real-time DR methods. Utilities transform into electricity service operators. Utility communication networks will undergo key changes through the adoption of a network architecture with virtualization, edge clouds, and network slicing and will also need to have shorter or continuous refresh cycles as the underlying communications technologies evolve. Digital value platforms will become an integral part of the utility operations technology with widespread automation powered by use of data analytics and artificial intelligence in new utility applications, and use of augmented intelligence systems in utility operations. We have characterized how the changes in utility applications, such as demand response, synchrophasors in the distribution systems, and utility workforce operations will be addressed with the evolution of digital platform and the future utility communications network architecture. New business models will be created including in response to expected regulatory changes; we have presented a new simple business model for customer billing in the utility of the future.

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References

[1] K. C. Budka, J. G. Deshpande, M. Thottan, "Communication Networks for Smart Grids – Making Smart Grid Real", Springer, 2014.

[2] M. K. Weldon, "The Future X Network – A Bell Labs Perspective", CRC Press, 2016.

[3] REN21 Secretariat, "Renewables 2017 Global Status Report", Renewable Energy Policy Network for the 21st Century, Paris, 2017., http://www.ren21.net/wp-content/uploads/2017/06/17-8399_GSR_2017_Full_Report_0621_Opt.pdf

[4] US Department of energy, "SunShot Vision Study", Solar Energy Technologies Office, February 2012. https://energy.gov/sites/prod/files/2014/01/f7/47927.pdf

[5] https://energy.gov/eere/sunshot/sunshot-2030

[6] University of Michigan, "U.S. Grid Energy Storage Factsheet", Center for Sustainable Systems, August 2017.

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[7] https://electrek.co/2017/01/30/electric-vehicle-battery-cost-dropped-80-6-years-227kwh-tesla-190kwh/

[8] Kittner, et el, “Energy storage deployment and innovation for the clean energy transition”, Nature Energy, July 2017

[9] https://www.tesla.com/green-mountain-power

[10] https://www.independent.co.uk/news/world/australasia/tesla-giant-battery-south-australia-reduce-cost-power-outage-backup-system-fcas-a8348431.html

[11] https://www.teslarati.com/tesla-virtual-power-plant-residential-solar-powerwall-2-south-australia/

[12] http://ourenergyplan.sa.gov.au/virtual-power-plant

[13] UK Power Networks, “Future Smart: A Smart Grid for All”, consultation report, July 2017.

[14] NGMN Alliance, “NGMN Network Slicing “Description of Network Slicing Concept”, Available: https://www.ngmn.org/uploads/media/160113_Network_Slicing_v1_0.pdf.

[15] P. Rost, et el, “Network Slicing to Enable Scalability and Flexibility in 5G Mobile Net-works”, IEEE Communications Magazine, May 2017.

[16] H. Kim and M. Thottan, “A Two-Stage Market Model for Microgrid Power Transaction via Aggregators”, Bell Labs Technical Journal special issue on Vertical Markets, December 2011.

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