

A Digital Transformation at New York Power Authority



Digital Object Identifier 10.1109/MPE.2019.2959051
Date of current version: 19 February 2020

©ISTOCKPHOTO.COM/AISLAN13

Using Innovative Technologies to Create a More Efficient Power System

UTILITIES TODAY ARE FACING UNPRECEDENTED challenges due to more stringent regulations, environmental concerns, and a growing demand for reliable electricity. Meanwhile, according to U.S. Department of Energy's statistics, 70% of the grid's transmission lines and power transformers are more than 25 years old. Without upgrades and enhancements, the grid will continue to age, increasing the risk of service interruptions and limiting the integration of renewable resources. It will also be severely challenged by the intermittency of supply and the uncertainty in load.

Fortunately, many innovative and powerful new digital technologies, some of which were developed by other industries, have the potential to drastically improve the way electric power systems are designed and operated. Driven by these dynamics, utilities, technology vendors, and governmental organizations have created a vision of the next "smarter" generation of energy delivery systems. The key drivers of smart grid implementation include the need to prepare the grid for the challenges of a changing energy transmission and distribution landscape, accommodating increasing levels of renewable generation, improving system efficiency, reducing grid operation costs, boosting reliability/resiliency, and enhancing system security.

New York Power Authority (NYPA) is the largest state-owned utility in the United States and owns and operates close to 6,000 MW of generation, mostly hydroelectric, and 1,400 circuit miles (roughly 2,300 km) of bulk power transmission from 765 to 115 kV throughout New York State, as displayed in Figure 1. NYPA began a series of strategic initiatives in 2014 aimed at addressing the challenges that electric utilities face at multiple

levels, developing a Vision 2020 Strategic Plan for the next six years, and defining the optimal transformation path for adapting to this dynamic environment. In New York, these efforts support the state's Reforming the Energy Vision strategy for building a cleaner and more resilient and affordable energy system for all New Yorkers.

A vital part of this effort was the introduction of the Infrastructure Modernization Strategic Initiative, which centers on two areas: smart generation and transmission (smart G&T) and asset management. Smart G&T focuses on deploying innovative technologies, e.g., advanced sensors, high-speed communication systems, monitoring systems, and digital control schemes, which could increase situational awareness as well as the operational effectiveness, efficiency, and reliability of assets. The asset management initiative seeks to develop appropriate processes and procedures that improve the way the utility utilizes its assets, resulting in enhanced decision making for its day-to-day operations as well as future investments. This, in turn, would result in improved operational efficiencies and thus the creation of value for the utility and its customers. In a sense, the smart G&T initiative focuses more on the implementation of the foundational technical aspects, which would enable the asset management initiative to achieve its objectives.

These two complementary initiatives are expected to pave the way for increased benefits to customers by providing a market-leading platform for future technologies and services by developing capabilities in the following six areas:

- ✓ increased reliability and resiliency
 - advanced transmission monitoring, control, and protection systems that decrease the likelihood of cascading failures and wide-area blackouts
 - robust security measures that reduce the likelihood of catastrophic bulk system failures from human-caused and natural disasters.
- ✓ enhanced situational awareness
 - advanced analytical tools used for converting data from grid sensors into insight, leading to wide-area situational awareness and control capabilities

By Bruce Fardanesh, Adam Shapiro, Philip Saglimbene, Ricardo DaSilva, George Stefopoulos, and Ahad Esmailian

- improved operator effectiveness and enhanced system protection and restoration.
- ✓ optimized transmission assets
 - ensured flexibility and efficiency by optimizing the utilization of transmission assets
 - reduced congestion and bottlenecks, which lessen the costs of operation- and maintenance-related tasks
 - reduced risk due to old equipment or necessary downtime, which increases system efficiency.
- ✓ optimized generation assets
 - automatic controls and predictive maintenance cycles on existing generation facilities to maximize performance.
- ✓ the integration of bulk renewables
 - the development of bulk renewables that meet environmental policy requirements by using intelligent monitoring, climate microforecasting, protection and control technologies, storage technologies, and advanced information and operational technologies integrated with the underlying assets.
- ✓ the integration of distributed generation
 - the ability to manage distributed generation and storage to help balance the intermittency of renewable resources and provide grid support

- advanced system protection to manage intermittency and bidirectional power flow
- an advanced energy management system that integrates distributed generation with central resources.

NYPA's digital transformation revolves around the implementation of projects that support five fundamental steps. These steps are typically common across many smart grid deployments:

- ✓ deploying a dedicated utility-owned and controlled high-speed communications platform
- ✓ installing sensors and other intelligent electronic devices (IEDs) across the grid, which are used for collecting system and equipment sensory data
- ✓ rolling out enhanced grid control devices
- ✓ effectively using analytics, computational algorithms, and simulations for asset performance optimization
- ✓ ensuring secure deployment of all the aforementioned components.

NYPA is planning to deploy a variety of technical solutions that will create a range of benefits for both the company and New York State at large by following these five steps. To prioritize the most beneficial, cost-worthy elements of smart grid technologies and to ensure that the investments made

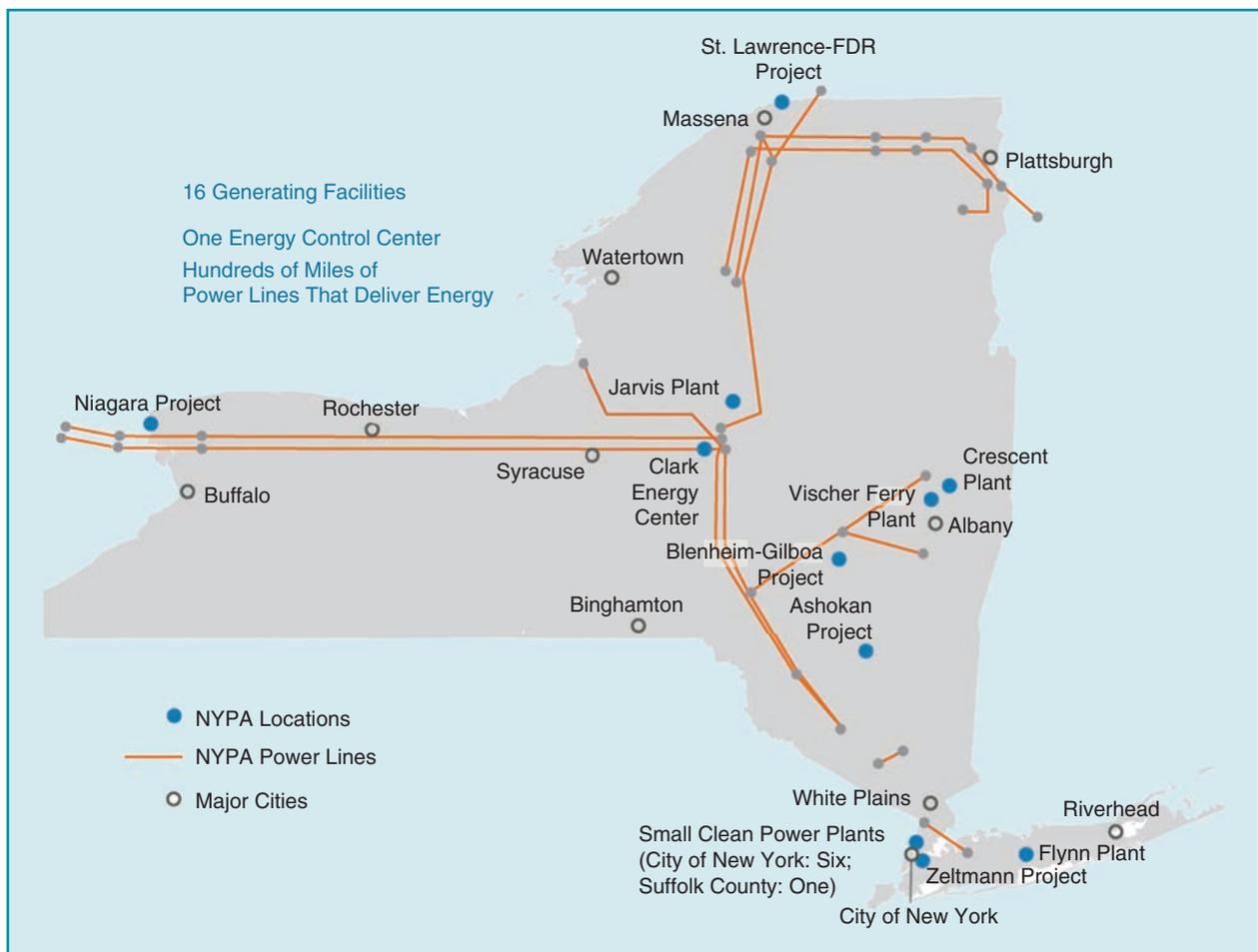


figure 1. NYPA's generation and transmission assets within New York State. (Source: NYPA; used with permission.)

will be prudent, the necessary capability areas were first recognized and the technical solutions under those areas were then identified. This approach allows for the development of the most appropriate business, organizational, or technical response to the changing utility industry landscape. The following sections of this article provide additional details of these projects.

Communications Backbone

The Communications Backbone project aims to deploy a robust, secure, and scalable communications network controlled by the utility (as opposed to third-party providers) and will achieve the following objectives:

- ✓ replace the legacy point-to-point circuits
- ✓ accommodate the data flows resulting from the increasing number of intelligent electronic devices deployed through the smart G&T initiative
- ✓ enable the advanced capabilities of the Integrated Smart Operating Center (iSOC), a separate project to be described in more detail later in this article.

The existing legacy communications technologies offered by third-party service providers are becoming obsolete and phased out by the carriers. The support and maintenance of such legacy service offerings (e.g., telephone lines and 56k circuits) are becoming more challenging and costlier, thereby forcing users to replace such technologies. Migrating to a new communications backbone is projected to be the most cost-effective solution in the long run.

The project also enables the following applications:

- ✓ phasor measurement unit (PMU)-based wide-area monitoring, protection, and control applications
- ✓ more advanced protective relaying schemes, such as differential line protection using a direct fiber connection or double-ended traveling wave protection and fault location
- ✓ the large-scale deployment of field sensors such as dissolved gas monitoring systems, temperature sensors, humidity sensors, weather stations, infrared (IR) cameras/sensors, condition monitoring systems, generator partial discharge (PD) monitors, vibration monitoring systems, and alarm monitoring systems
- ✓ real-time video surveillance used for physical security or other monitoring applications
- ✓ real-time drone footage transmission.

Given outlined requirements, a combined fiber and microwave backbone network is being deployed to accommodate



figure 2. An aerial installation of optical ground wire. (Source: NYPA; used with permission.)

operational and business data communication needs. The fiber portion consists of a hybrid solution using utility-owned optical ground wire, which is being deployed along major transmission corridors (see Figure 2) as well as leased existing unutilized fiber from other providers, typically referred to as dark fiber. This leased dark fiber portion is fully dedicated to the utility's use, thus providing all of the functional advantages of an owned solution while minimizing deployment costs and optimizing investments. The microwave portion of the network is being constructed as a diverse backup system or a primary system at locations with lower bandwidth requirements or where existing dark fiber is not available and new fiber deployment is not economically feasible. This would be the case in regions where NYPA operates generation assets but does not own transmission infrastructure. The newly constructed microwave system will be integrated with the existing microwave infrastructure, which, in turn, is also being upgraded to meet the desired performance characteristics. Table 1 lists some details of the Communications Backbone project implementation.

Continuous Protection System Monitoring

Continuous protection system monitoring (CPSM) is an uninterrupted ac current and voltage monitoring system of digital relays that complies with North American Electric Reliability Corporation (NERC) PRC-005-2 Protection System Maintenance requirements. The current and voltage signals measured by microprocessor-based protection relays will be continuously monitored and verified by comparison to an

table 1. NYPA's Communications Backbone project implementation details.

| Optical Ground Wire (OPGW) | Dark Fiber Lease | Microwave |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> • 100-Gb/s bandwidth • 1,080+ km of utility-owned OPGW installation; 48-strand fiber • Currently 11% complete; construction scheduled for completion in 2021 | <ul style="list-style-type: none"> • 1,610+ km of leased dark fiber • Currently 40% complete • Construction scheduled for completion in 2020 | <ul style="list-style-type: none"> • 300-Mb/s bandwidth • 400+ km of microwave coverage • 28 microwave towers • 65 microwave dishes |

independent source, making it possible to alarm for unacceptable errors or failures. The benefit of installing CPSM functionality at NYPA stations relates to reducing asset operation and maintenance costs. The continuous automated monitoring of protection systems will both reduce the frequency of unnecessary time-based maintenance and associated labor and travel costs as well as result in efficiency gains during maintenance by providing real-time, standardized, and reliable guidance and evaluation for maintenance activities, which are typically labor- and time-intensive tasks. As a result, this helps to reduce the risk of major failures while increasing overall reliability in a consistent manner across existing protection systems.

The continuous automated monitoring of protection systems will also alert substation operators of real-time gradual degradation in the performance of the protective relaying system. This capability, when coupled with the state-of-the-art asset health monitoring and diagnostics center, could help mitigate the risk of prolonging fault conditions that cause major failures, e.g., transformer bushing failures, and thus reduce any costs associated with repair and replacement.

Digital Substation

As a major step toward enhancing its digital capabilities, NYPA has initiated several digital substation implementations using projects of various scales and scopes. The digital substation concept involves digitizing a portion of the substation secondary system by eliminating the majority of ana-

log secondary circuits between the instrument transformers and protective relays. IEC 61850, *Standard for Communication Networks and Systems in Substations*, is the framework around which a digital substation is built. By connecting the various pieces of field equipment, e.g., circuit breakers, protective relays, current transformers (CTs), and potential transformers (PTs) using optical fiber cables, the substation layout becomes simpler, several safety issues are mitigated, and, the implementation becomes more cost-effective in the case of a new substation construction.

The IEC 61850 optical network operates using the Ethernet protocol. Within this framework, traditional status and command signals are transmitted using a generic object-oriented substation event (GOOSE). GOOSE is a specific formatting of data that enables protection status signals to be transmitted within 4 ms. This is essential to ensure the reliable and timely operation of interconnected IEDs.

Figure 3(a) and (b) shows the dual-redundant station and process bus in a digital substation, which provides greater reliability for critical substations as compared to a single process bus. The station and process bus systems are implemented using external Ethernet switches, connected together in a ring configuration. The station bus allows for signals to be exchanged between the bay-level IEDs and station control, while the process bus allows communication between the bay-level IEDs and field devices, transducers, and other equipment. Merging units (MUs) are used to collect signals from various pieces of field equipment, including

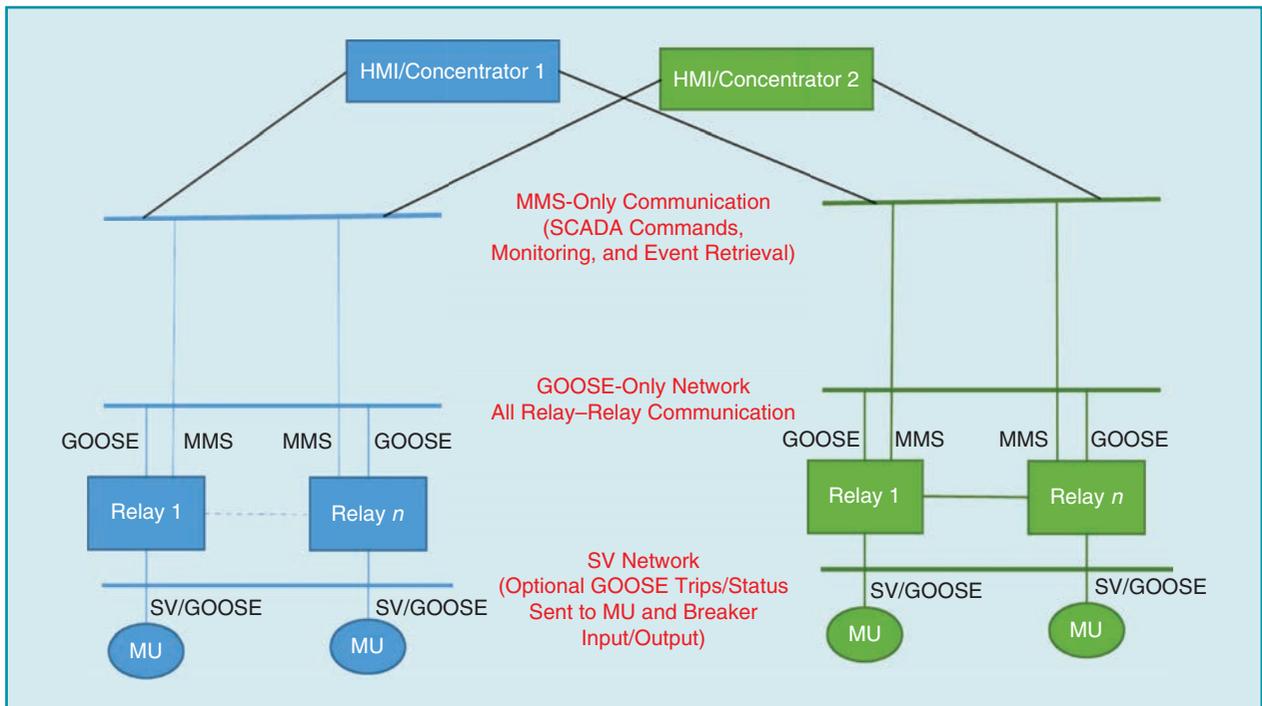


figure 3. A dual redundant station and process bus architecture. HMI: human-machine interface; MMS: manufacturing message specification; SCADA: supervisory control and data acquisition; SV: sampled value; MU: merging unit. (Source: NYPA; used with permission.)

CTs and PTs. These signals are then digitized and transmitted via the process bus to other devices as sampled values (SVs). The merging unit is the interface between the traditional analog signals and the digital protective relays and other IEDs. As opposed to the publisher/subscriber methodology used by the GOOSE and SV protocols, the manufacturing message specification (MMS) protocol is based on a client/server mechanism and typically used for higher-level, one-to-one information exchanges, such as those between a substation and a supervisory control and data acquisition system.

There are currently three ongoing projects that look to incorporate digital substation architectures into existing transmission substations. The first implementation is the switchyard automated monitoring and controls system being installed at the 115-kV switchyard of the Robert Moses Saint Lawrence Power Project, one of NYPA's major hydroelectric plants. The project involves the implementation of a GOOSE process bus and GOOSE messaging between relays as well as MMS stations, while maintaining traditional hardwired connections between the relay building and the switchyard CTs and PTs. A second project, which has already been commissioned and is operational, involves fiber-optic CT installations and the implementation of an SV network at the Fraser Annex substation, located in central New York. The substation houses a series capacitor bank operating on a 345-kV transmission corridor. Finally, work is currently being done on a more comprehensive IEC 61850 project as part of a major upgrade of a 115-kV substation in northern New York. The project includes optical CT and PT installations for line protection relaying, the installation of field merging units, and the implementation of SV and GOOSE schemes in both process and station bus arrangements.

The digital substation offers the following advantages over a conventional arrangement:

- ✓ easier and simpler installation (much less wiring)
- ✓ interoperability between devices made by different manufacturers
- ✓ improved reliability
- ✓ improved measurement accuracy and recording of information
- ✓ improved commissioning and operations
- ✓ easy incorporation of modern electronic CT and PT sensors.

Wide-Area Deployment of PMUs

Initiated in 2016, the purpose of this project was to install new PMUs that extend the system observability of the existing PMU network and also replace several vintage devices installed in the early 1990s. These PMUs provide valuable phasor data, which support the enhanced real-time monitoring and operation of the grid and, when combined with other analysis and control tools, help increase power flows over existing interfaces, alleviate congestion, and improve grid reliability.

Conventional techniques of operating and monitoring the bulk grid have limited capabilities for real-time problem detection and failure prevention. This means that there would not be enough time to react to fast-evolving events that threaten the stability of the system. As a result, the bulk power grid operates under conservative assumptions that do not allow for operating the system based on its real-time dynamic limits, resulting in congestion and inefficient asset utilization. This becomes increasingly relevant and important as intermittent resources are integrated into the grid, thus reducing the controllability and predictability of available generation. Also, as more advanced and complex control schemes are embedded into the grid (e.g., power electronic-based interconnections), faster transient phenomena are expected to have a more profound effect on grid operations.

In a future hierarchically centralized and coordinated grid operation and control scenario, one can envision that sufficient, synchronized, low-latency, and trustable (cyber-secure) data (including breaker status or network topology data) with adequate sampling rates will be widely available at the operations/control center and the state estimator (the backbone of all energy management system applications) will run with a superior performance in the subsecond even-cycles timeframe, providing full knowledge of the system state. This full-state knowledge enables very fast contingency ranking and security analysis and control action determination, providing timely advice to the system operator under both normal and emergency conditions. In the long run, as confidence is built, some of these control actions may be performed automatically via direct feedback from the operations/control center. For additional grid flexibility, ultimately, such closed-loop automated capabilities will be indispensable for operating power systems more reliably, safely, and efficiently, especially in dealing with fast power system phenomena and zero- or low-inertia, inverter-based generation resources.

The phasor data captured during grid disturbances will also be used to perform system model validation for NERC regulatory compliance. Per NERC compliance requirements, generator owners must periodically validate the dynamic models of large generating units. This can be performed via offline tests or by utilizing captured PMU data during system disturbances. Offline, manual validation is costly, more tedious to perform, and requires units to be taken out of service, whereas automatic validation using PMU data will be more efficient and cost-effective.

Fleet-Wide Deployment of Smart Sensors

As a major part of its digitization initiative, NYPA is currently deploying additional sensors to collect data from power plant equipment, substation apparatus, and transmission lines to enhance efficiency and extend the life of those assets by continuously assessing their performance and condition status. A full suite of sensors is being installed on

equipment, e.g., turbines, generators, transformers, reactors, circuit breakers, battery banks, underground/underwater cables, and overhead transmission lines, as depicted in Figure 4. Sensors, e.g., dissolved gas analyzers, temperature, pressure, and vibration monitors, PD and acoustic sensing, IR cameras, dynamic line rating equipment, and icing and

galloping detection systems have been installed at the company's assets fleet wide. By networking these sensors to the iSOC, it is expected that more than 130,000 data points will be transmitted to this new monitoring and diagnostic hub. The iSOC currently collects more than 45,000 data points spanning the New York State grid and feeds the data into

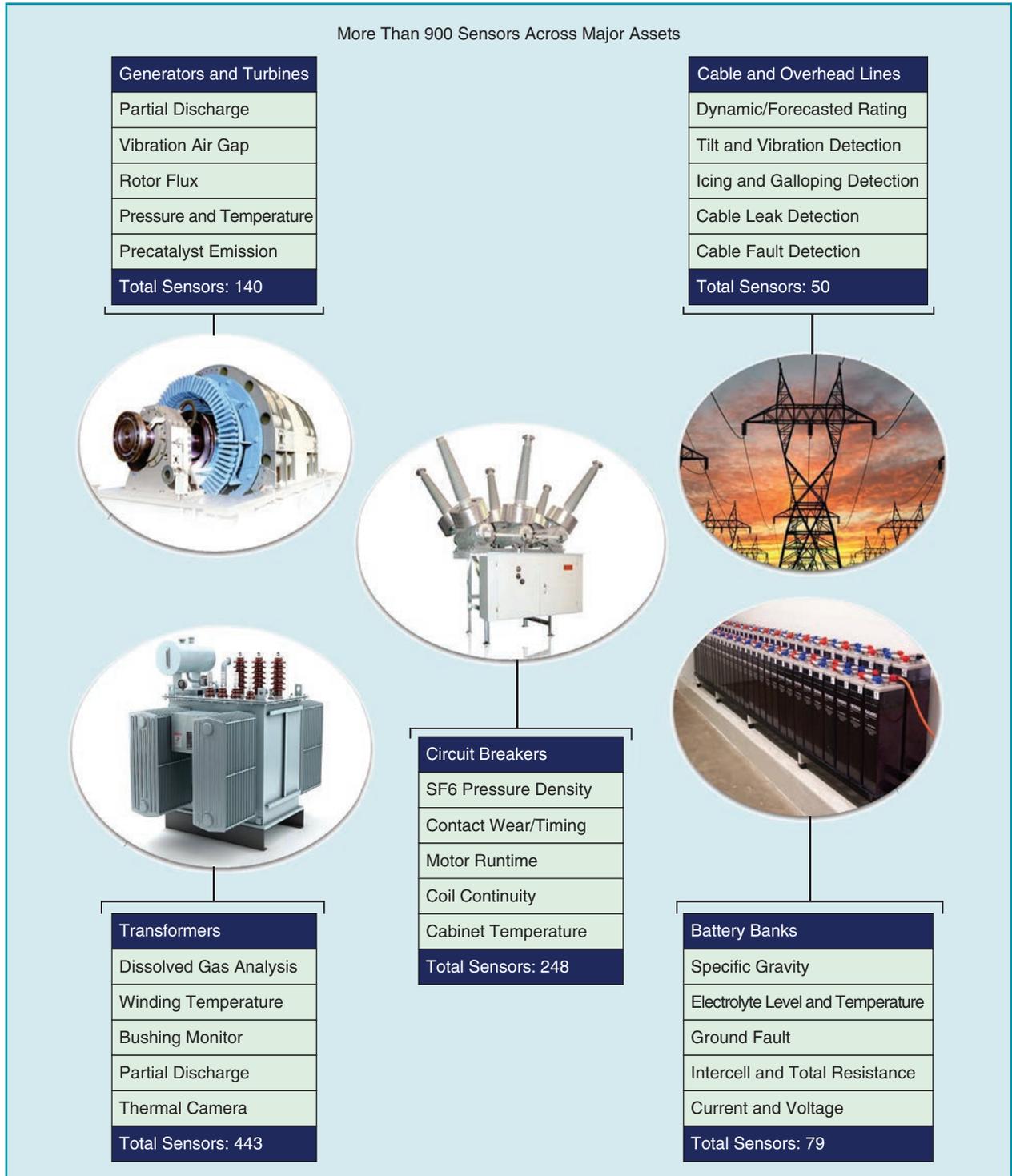


figure 4. The sensor types and total number of major assets. SF6: sulfur hexafluoride. (Source: NYPA; used with permission.)

state-of-the-art analytics engines. In the center, analysts and engineers look at the near-real-time performance of the various monitored pieces of equipment and compare it to their predicted performance, spotting potential issues often well before conventional scheduled preventive maintenance would detect them. The data shows up on an impressive 81-ft-long LED display screen, enabling iSOC staff to visualize various data from different sources concurrently and more effectively analyze and extract information from such data.

iSOC

The iSOC, located at NYPA's offices in White Plains, New York, is a cutting-edge comprehensive central monitoring center, as shown in Figure 5. The center, which opened in December 2017, uses predictive analytics software to forecast and prevent equipment failures and significant outages at power plants, substations, and transmission lines, providing the technological ability to predict and remedy with a higher level of efficiency. This enables effective scheduling of repairs, lowers maintenance expenses, and reduces operating risks, thus helping the utility to keep costs down, translating to savings for its customers.

One of the fundamental goals of the asset management initiative is to harness improved decision-making capabilities by aggregating various sensory data streams to monitor, diagnose, and inform asset repair or replace decisions. Achieving this goal and realizing the associated benefits are reliant upon a robust integrated data analytics platform and decision support tools. Creating a strong data foundation that allows for data analysis, visualization, association, and sharing across the organization requires a combination of data cleanup efforts and the deployment of modern analytical and visualization tools. The iSOC provides enterprise-wide technology and service management capabilities across the company's operational groups and plays a critical role in identifying, managing, coordinating security incidents and events on common devices, infrastructure, networks, and applications where one or more operational groups have an interest.

A key feature of the iSOC, compared to more traditional utility monitoring and diagnostic centers, is its additional multifunctional, multidiscipline capabilities, which include the monitoring and management of communication networks and IT infrastructure as well as physical and cybersecurity. Such functionality variety is crucial for supporting the center's role as an integrated operations center. These diverse capabilities and functionalities hosted within the iSOC make it the central nervous system of the smart grid, constantly monitoring sensors, devices, and communication paths to alert and suggest corrective actions to an operator when faults or other problems occur. This increased awareness helps to streamline operational performance, reduce annual and unexpected operating costs, increase general asset performance and reliability across the fleet, and mitigate the impact of catastrophic events. This kind of cost reduction/

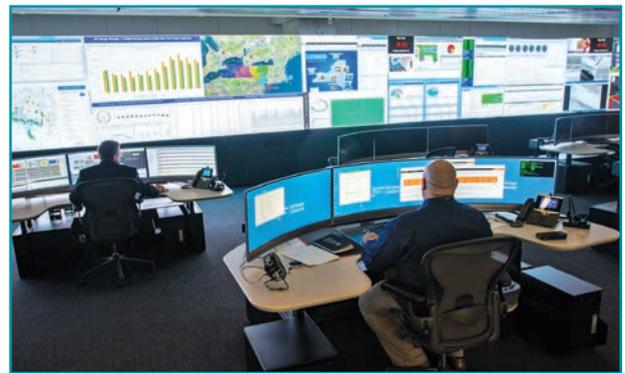


figure 5. The iSOC at NYPA's offices in White Plains, New York. (Source: NYPA; used with permission.)

avoidance and performance improvement is a fundamental driver of the benefits NYPA intends to achieve through its broader strategic plan.

A combination of predictive analytics tools using physics-based and machine-learning algorithms enables iSOC analysts and engineers to notice trends in how a piece of equipment is operating. The desired outcome of processed data aims to reveal valuable insights into any incipient problems and gauge the life expectancy of equipment based on historical and current operating patterns, which might differ from manufacturer specifications.

Predictive analytics also offers an opportunity for more sophisticated outage scheduling processes. For instance, if the data indicate normal performance, the manufacturer's calendar-based replacement or maintenance schedule could be reduced. Conversely, if the data indicate an issue with the health of an asset, then maintenance should occur before the next scheduled service. In extreme circumstances, the equipment can be shut down immediately to avoid a catastrophic failure that could result in loss of service for longer periods.

The iSOC may initially receive hundreds of advisories per day on potential service issues. With the trending data, analysts and engineers can determine what caused an alarm, what it means, and how it should be addressed. Most alarms may be inconsequential, but two or three instances may be focused on for further detailed examination. This supervised learning and tuning process would gradually reduce the number of false positive alarms as more data are collected over time.

Advanced Grid Innovation Lab for Energy

In pursuit of its digitization goals and to support the R&D effort required to face the challenges of digitization, NYPA has launched the Advanced Grid Innovation Lab for energy (AGILE). Established in 2017 as a collaborative initiative led by NYPA and supported by additional stakeholders, AGILE is a power systems laboratory that includes simulation and testing facilities. The lab provides electric utilities, governments, universities, high-tech businesses, and others



figure 6. AGILE, the power systems laboratory located at NYPA's offices. (Source: NYPA; used with permission.)

from around the world with a wide range of R&D tools. The research work performed in the lab can help strengthen infrastructure, fast track the commercialization of new technologies, and expand renewable energy integration. The work performed at AGILE will accelerate improvements to New York's energy infrastructure and lead to a more reliable and efficient electric grid.

The specific general research areas at AGILE include advanced transmission applications, cybersecurity, substation automation, sensors, and power electronics controllers. AGILE is located at the White Plains offices, as shown in Figure 6, and comprises a digital real-time grid simulation lab, which will enable real-time simulations of New York State's electrical grid. It is initially targeting transmission- and distribution-level research focusing on power system wide-area monitoring and control, synchrophasor applications, renewable energy integration, and substation automation and control. AGILE has the potential to provide grid benefits, e.g., accelerating and streamlining the deployment of new equipment and technologies, analyzing peak demand stress, incorporating intermittent resources, and improving reliability and bulk system control.

The lab will help deliver the following capabilities and outcomes:

- ✓ advanced modeling of power grid components
- ✓ real-time simulations of New York State's electrical system
- ✓ hardware-/software-in-the-loop equipment testing
- ✓ the emulation and performance characterization of power grid data communication schemes
- ✓ automated controls that improve network resiliency, security, safety, and efficiency
- ✓ the integration of large-scale renewable energy resources as well as distributed energy resources
- ✓ a high level of situational awareness that enables optimal grid operation under various conditions.

It is envisioned that AGILE will create a collaborative research environment that brings utilities, academic institutions,

technology vendors, and research organizations together to work on common challenges and opportunities that can improve the performance, security, and efficiency of the electricity grid.

Summary

Like other utilities, NYPA has embarked on a digital journey in technical areas of grid monitoring/operations/control as well as business enterprise to take advantage of the efficiencies from the effective use of information and data. Although this is a bold endeavor for a conservative industry in terms of adopting new technologies, the benefits are starting to be realized through asset health and longevity enhancements, operation and maintenance and capital savings, and enhanced tools and methodologies for grid operation and control. This journey is envisioned to ultimately result in a safer, more reliable, more secure, and more efficient power system.

For Further Reading

"Infographic: Understanding the grid," U.S. Department of Energy, Washington, D.C., Nov. 17, 2014. [Online]. Available: <https://www.energy.gov/articles/infographic-understanding-grid>

B. Fardanesh, "Future trends in power system control," *IEEE Comput. Appl. Power*, vol. 15, no. 3, pp. 24–31, 2002. doi: 10.1109/MCAP.2002.1018819.

S. Ghiocel et al., "Phasor-measurement-based state estimation for synchrophasor data quality improvement and power transfer interface monitoring," *IEEE Trans. Power Syst.*, vol. 29, no. 2, pp. 881–888, 2013. doi: 10.1109/TPWRS.2013.2284098.

B. Fardanesh, "Direct non-iterative power system state solution and estimation," in *Proc. IEEE Power and Energy Society General Meeting*, San Diego, CA, July 2012, pp. 1–6. doi: 10.1109/PESGM.2012.6345757.

"Smarter energy infrastructure: The critical role and value of electric transmission," Edison Electric Institute, Washington, D.C., Mar. 2019. [Online]. Available: <https://www.eei.org>

Biographies

Bruce Fardanesh is with the New York Power Authority, White Plains.

Adam Shapiro is with the New York Power Authority, White Plains.

Philip Saglimbene is with the New York Power Authority, White Plains.

Ricardo DaSilva is with the New York Power Authority, White Plains.

George Stefopoulos is with the New York Power Authority, White Plains, New York.

Ahad Esmaeilian is with Avangrid, Orange, Connecticut.

