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substation innovations

the heart and brain of the grid

SUBSTATION MODERNIZATION remains a critical element of state-of-the-art electric power systems. The rapidly evolving nature of the grid, customer demands, and technological innovation puts substations at the forefront of grid transformation. Substation developments include the application of equipment tests, sustainable practices, digitization, and advanced solutions for a host of system needs, along with reactive power compensation and long-distance renewable integration of renewable energy sources. Substations must increasingly act not only in the interest of the larger grid but also in support of decision making at the local level. They are expected to serve as data-gathering locations that can optimize future investments leading to the implementation of new technologies. To achieve public acceptability, substations should be fully functional and either invisible or aesthetically appealing, especially in highly populated areas. Sustainability is another aspect where substations are seeing innovation, such as in replacing sulphur hexafluoride (SF6) gas, a greenhouse gas, with other gasses used in compact gas-insulated substations (GISs).

As Ramy Azar writes in his "In My View" column, substations are becoming the heart and the brain of the electric grid. The pace of innovation in substation design is accelerating quite significantly, and we should not be surprised if we see self-healing substations managed by artificial intelligence (AI) in the near future.

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With the substation of the future in mind, we invited authors from across the globe to share their experiences and expertise regarding technologies being implemented in their regions. It should not come as a surprise that advancements in substation technologies play a key role in the next evolution of the grid.

Our first article, by Heejin Kim, Jae-Kyeong Kim, Jiyoung Song, Jaegul Lee, Kisun Han, Jeonghoon Shin, Taekyun Kim, and Kyeon Hur discusses sustained R&D solutions that create more sustainable and smart substations throughout the Republic of Korea. The benefits of these efforts include reduced adverse environmental impacts of substations, while, at the same time, implementing cutting-edge technological innovations continuously improves the performance of existing and new assets. The authors start with a brief description of the growth history of the electric transmission and distribution system on the Korean Peninsula. They examine the adaptation and implementation of the IEC 61850 standard in substations. Kim et al. share the additional research being done for the development of AI algorithms to be used for automatic restoration of equipment. They then describe the establishment of advanced data collection infrastructure and how it is expected to lead to more reliable service for the end customers. With a significant push to integrate renewable resources in Korea, the authors review a standard modularized green substation that is easily deployed and also uses inert gases for insulation rather than SF6. As mentioned in the article, deploying a standardized modularized substation, which may also include flexible ac transmission system (FACTS) devices, could significantly promote the successful integration of distributed energy resources (DERs) and microgrids.

In the second article, George Zhou, David Wang, Adham Atallah, Frank McElvain, Ram Nath, John Jontry, Christopher Bolton, Huang Lin, and Andreas Haselbauer survey synchronous condensers. They provide an in-depth look at the significant portfolio changes that a number of U.S. states are facing with increased renewable portfolio standards (RPSs), which encourage the development of carbon-free electric energy resources. An unintended consequence of RPSs has been the closure of some nuclear power plants earlier than expected due to reduced revenues caused by the addition of lower-cost variable resources. The article evaluates the effects of the loss of kinetic energy and reactive power supply on large power systems, like California's, which have integrated renewables at a large scale. The authors explore some technical studies that were done to evaluate system conditions, including power flow and transient analysis, and how innovative solutions can improve system reliability.

Modeling issues and the need for proper representation of equipment are also evaluated, an aspect the industry views as vitally important. Flawed models used in the initial project evaluations were uncovered only after equipment installations had resulted in deficient performance, which added substantial costs. As the authors point out, synchronous condensers are one of many devices that can improve system performance by addressing variability issues resulting from the high penetration of renewable resources. The studies highlighted in the article are also needed for planning other types of FACTS devices, and in all cases, they provide the information necessary for ensuring the appropriate design of equipment that meets grid support requirements.

The next article, by Rich Hunt, Byron Flynn, and Terry Smith, describes a digitally enabled substation, its architecture, and areas of development. It builds on the discussion in the first article by Kim et al., regarding the digitalization and modularization of the substations. The authors show the advantages of a digitally enabled substation that can readily adapt to increased levels of inverter-based DERs and electric vehicles while providing improved control of the power system at the local distribution feeder level. Given the many-fold increase in the number of stakeholders participating in the production and distribution of electricity, the authors believe that utilities would optimize grid investment by interacting with each stakeholder and leveraging system data. This would require a larger amount of flexibility in the power control system. To that end, the authors explore the architecture of the digitally enabled substation that would provide the required adaptability and flexibility. They expect a variety of applications running on a software platform that would provide a wide range of services based on the sensing data from the substation and the larger network. Stakeholders, such as utility operators, would need to interact with potentially thousands of devices and improve situational awareness required to operate the system reliably and efficiently. As the power system becomes more unpredictable with less hierarchical control, situational intelligence can be obtained using a variety of monitoring systems, ranging from wide area monitoring systems to small monitoring sensors on the equipment measuring the operational reliability of the power system equipment. All the collected data would then need to be organized, evaluated, and utilized for substations to operate reliably and almost independently.

Hunt et al. discuss steps that the industry would need to take to support the digitization of the substation and the status of standards, available hardware, and initial adoption by industry. They address the process bus design in detail, including process interface units, which would exist close to the primary equipment and act as the interface between the digital systems and power system equipment. Other pieces of equipment may be replaced by digital instruments that reduce overall cost, improve accuracy, and enable better system protection. With increased accuracy, analytics-based asset management systems could improve predictive maintenance equipment models by identifying issues sooner than is currently possible. The digital substation results in a smaller physical footprint and adds additional flexibility to the assets. Gathering data from the substations is also expected to deploy even more DERs by being better able to visualize the local needs and drive investment strategies by various stake holders. Relevant issues around cybersecurity and workforce development are also discussed because they will influence the adoption rate of new technologies by investor-owned utilities.

The fourth article, by Dirk Van Hertem, Willem Leterme, Geraint Chaffey, Mudar Abedrabbo, Mian Wang, Firew Zerihun, and Mike Barnes, brings to the forefront the discussion around dc technology and its application in substations of the future. The authors begin by describing applications of two current converter station technologies: line commutated converters (LCCs) and voltage source converters (VSCs). High-voltage (HV) dc applications have grown to meet the need for the bulk energy transfers from generation sources to population centers, as is evident in China, India, and Latin America. HVdc technology also supports the integration of large-scale renewables, such as offshore wind resources that are primarily connected through underground/subsea cross-link polyethylene cables. The discussions on ac/dc conversion equipment highlight the challenges surrounding propagation of fault currents and the equipment that can be used to interrupt fault current at the converter. An examination related to dc circuit breakers and switchgear is followed by various mechanisms that can be utilized for dissipating excess energy. The development of new dc power-flow control devices enables use of the full capacity of the power system network, but it could increase the land area requirement for substations. Secondary equipment, such as nonconventional instrument transformers for dc voltage measurement, is also being developed and is expected to support the development of dc substations.

In the context of grid control for stable operations, the authors talk about the potential to employ a voltage droop scheme at the substation level utilizing a grid controller concept. Increased integration of intelligent electronic devices using the IEC 61850 protocol and other standards for communication and teleprotection for the dc substations will also need higher bandwidth and communication speed, which will require us to rethink how we deploy communication networks. This is expected to lead to the development of digital platforms for dc grids, echoing the message we heard from Hunt et al.

Considerations for dc substation design, influenced by the choice of substation technology, bus bar design topology, and protection philosophies, are also detailed by the authors. Offshore dc substations primarily use VSC technology, which requires a smaller footprint and lower installation costs than LCC installations. Other considerations for offshore dc substations relate to weather conditions, implementation logistics, spare part philosophies, access to substations, and revenue loss analysis that takes into account forced and maintenance outages. We see the drive to reduce offshore installation weights leading to tradeoffs between efficiency and amount of equipment. Cooling systems for HVdc converter stations add weight and can lead to interesting applications of dc GIS solutions for the offshore substations (OSSs), which do not require significant cooling systems.

The fifth article, by Vandad Hamadi, Úna Brosnan, Ingar Loftus, and Gavin Montgomery, who are all from the United Kingdom, discusses the lifecycle optimized approach to OSS design in Europe. OSSs have been built in Europe for a few years and are now starting to be deployed globally as offshore wind installations continue to grow. They play an important role as collector stations of offshore wind resources by stepping up the voltage to onshore substation connections. The United States expects offshore wind resources to reach an installed capacity of 8.4 GW by 2030, with more than 30 GW in planning and development stages. Offshore wind developers have experienced significant pressure to reduce overall installation costs, including capital costs (CAPEX) and operational costs. Lifecycle cost management for OSSs affects revenue models, which consider costs of transmission losses and reduced availability due to repairs. The overall CAPEX costs of the HVdc installations become more favorable than ac alternatives for offshore projects that are far from land.

An innovative approach of the offshore transmission module (OTM) strips down the OSS equipment to a bare minimum. The OTM weight reduction is achieved by using automated controls. Integrated offshore HVdc and HVac substations and interlinked OSSs offer opportunities to reduce overall costs, which could portend offshore grids driven primarily by economic considerations. The technological advances helping the industry to further improve OSS design include increases in array cable voltages, adopting midpoint reactive compensation platforms, larger wind turbines, structure standardization, and the use of GIS equipment. Technologies currently under development include low-frequency ac systems, floating substations, offshore development hubs, and submerged substations. These technologies have the potential to reduce the cost even further for offshore wind developments. New onshore substation designs can utilize many of the OSS technological and economical improvements.

Engineers consider construction and operational issues as part of the design and installation of projects. This is particularly true for OSSs, where maintenance costs grow exponentially once the substations are transported offshore. Onshore testing and verification prior to transport is an important aspect. Much of OSS maintenance resembles practices of the oil and gas industry, which has extensive experience with offshore structures and some electrical assets. The challenge is determining typical maintenance requirements for different types of electrical equipment in an offshore environment. A strong case can be made for condition-based maintenance to reduce the lifecycle costs of the asset.

Another key consideration is the final decommissioning of assets after end of life. This is not a typical consideration for onshore substations where life extensions are typically less expensive than complete replacement or decommissioning. Offshore projects, however, are typically required to remove all assets that have been installed. We can be sure that there will be development of new practices for OSSs leading to innovative solutions in the next decade to come.

The "In My View" column provides a perspective on how current technologies will shape the future development of substations. The author describes substations as the main components of electric grids and reflects on the critical role electricity plays in keeping the engines of economies going and growing. He also reflects on the need to alleviate energy poverty, an area where substations play an important role alongside the DERs. He studies the improvements in computing power that have enabled the rise of microprocessor-based relaying and have led to improved protection systems, which exhibit better reliability, selectivity, speed, cost, and simplicity.

These improvements have also led to the growth of software platforms that are slowly replacing the need for large physical equipment by utilizing what is currently considered nonconventional equipment. This is anticipated to reduce overall substation sizes and have a positive environmental impact. Azar also talks about the rise of AI and its potential to create self-managing and self-healing substations, which give rise to more efficient, reliable, and safe systems. In addition, the author investigates how virtual reality technologies can further improve the substation design. The vision of a substation being a Wall Street trading floor for electricity of the future is the most graphic description of the potential changes we will see in the industry in the near future.

The future looks interesting for substations utilizing new technologies, showing better aesthetics and sustainability, and providing increased ability to integrate DERs. The development of substation innovations will provide opportunities for professional growth in the electric power industry for years to come, especially as we learn to gather, understand, and improve how we manage and use data that will be available from the substations. I look forward to further discussions of substations of the future at IEEE Power & Energy's 2019 General Meeting.

This issue contributes to the discussion of state-of-the-art innovation in substations and the future path that it can possibly take. I would like to thank the authors for their time and dedication and the articles provided, which shed light on innovations happening around the world. And a special thanks to the IEEE publications staff and Editor-in-Chief Michael Henderson for all of the assistance rendered to a novice guest editor.