COMPLEX SYSTEMS ARE COMPOSED OF MANY ELEMENTS. ARCHITECTURE CONCERNS ITSELF WITH HOW TO MANAGE THE ENTIRE ENSEMBLE OF ELEMENTS THAT MAKE UP A SYSTEM. WHEN WE THINK OF AN ARCHITECTURE FOR ELECTRIC POWER SYSTEMS, THE CONCEPTS NEED TO GO BEYOND ADDRESSING HOW THE ELEMENTS OF THESE SYSTEMS INTEROPERATE EFFECTIVELY AND EFFICIENTLY. THEY MUST ALSO INCLUDE HOW THEY GROW AND EVOLVE, HOW THEY BEHAVE UNDER STRESSES AND STRAINS, AND IMPORTANTLY, HOW THEY OFFER OPTIONS FOR FUTURE DECISIONS IN AN UNCERTAIN WORLD.

THREE GROUPS OF FACTORS ARE DRIVING CHANGE TO OUR POWER GRIDS.

✔ CHANGING CONSUMER EXPECTATIONS: In the era since the introduction of the smartphone, consumers expect vastly expanded choice and ease of use. These expectations have extended to energy sources. Consumers want not only to be able to choose an energy source but also to be able to easily obtain information related to energy use.

✔ EMERGING TRENDS: These include technology trends, such as the availability of ubiquitous communications, but also demographic/social trends, such as the movement toward local choice in all things, including electricity sources, as indicated by the rise of microgrids and community choice aggregators. On the negative side, the rise of cybersecurity issues that come with ubiquitous communications threatens our energy security.

✔ THE SHIFT FROM CENTRALIZED ELECTRICITY ECONOMIES OF SCALE TO DISTRIBUTED NETWORK ECONOMIES: Twentieth century power grids were developed under the assumption that all electricity would be generated by large centralized dispatchable generators, and these, connected via transmission to local distribution systems, would provide a one-way flow of energy to consumers. The emergence of rooftop solar photovoltaic panels and other forms of distributed generation connected at the distribution level and the rising availability of electric energy storage are changing the economics of electricity generation and use.


ARGUABLY, THE MOST COMMON SYMBOL PEOPLE ASSOCIATE WITH OUR PROFESSION IS THE PLUG, WITH THE WALL SOCKET NOT FAR BEHIND. THE ARCHITECTURAL PROWESS BEHIND THIS SIMPLE INTERFACE POWERS THE WORLD. IT SERVES TO DECOUPLE THE COMPLEX ISSUES ADDRESSED BY AN ENTIRELY DIFFERENT SET OF ELECTRICAL ENGINEERING SKILLS THAT HAVE EVOLVED, MOSTLY INDEPENDENTLY, OVER DECADES OF PROGRESS ON BOTH SIDES OF THE WALL. THE PLUG AND SOCKET ARE PRESENTLY UNDERGOING A TRANSFORMATION TO INCLUDE THE INTEGRATION OF COMMUNICATIONS. HOW FITTING IT IS THAT OUR SUCCESSORS MAY SEE THE USB PORT AS THE SYMBOL FOR A NEW ERA OF ENERGY AND INTELLIGENCE IN THE MODERN GRID. JUST AS MOST OF US GREW UP EXPECTING THE LIGHT TO GO ON AFTER WE PLUGGED IT IN, THE NEXT GENERATION IS EXPECTING THEIR APPLIANCES TO NOT ONLY “LIGHT UP” BUT TO COORDINATE WITH OTHER EQUIPMENT ON THE OTHER SIDE OF THAT OUTLET. THE TENDRILS OF COORDINATION GO FAR AND WIDE, AND THEY DEEPLY DEPEND ON OUR ABILITY TO MANAGE THE COMPLEXITY USING ALL OF THE ARCHITECTURAL SKILLS WE CAN MUSTER.

In This Issue

Coeditor Jeffrey D. Taft kicks off this issue with “Grid Architecture: A Core Discipline for Grid Modernization.” This article introduces grid architecture as a powerful set of tools to tame the expanding complexity of the far-reaching facets that make up modern electric power systems. To better view and understand the systemic qualities of electric systems, we must somehow rise above the details of all of the things that contribute to its makeup. This leads to an
emphasis on structures, clear definitions of concepts, general principles inherent in successful architecture, and methods that facilitate the development of good architecture. As information and communications technology pervades grid infrastructure, our electricity sources, the end uses, and the interaction processes that bind them, grid architecture is critically needed as a source of perspective and insight.

In the article by Paul De Martini, “Operational Coordination Architecture,” transmission/distribution coordination architectures from around the world are surveyed and analyzed using grid architecture principles. This issue is of global significance and relates directly to the distribution system operator concepts being worked on widely in the power industries of many countries.

In “Hawai‘i’s Grid Architecture for High Renewables,” Marc Asano from the Hawaiian Electric Companies (HECO) describes the challenges faced by HECO due to the high cost of traditional electric generation and the rapid adoption of renewable energy sources, including distributed sources. His article shows how HECO applied grid architecture in the development of its grid modernization plans and technology choices.

“The Plug-and-Play Electricity Era: Interoperability to Integrate Anything, Anywhere, Anytime” by Widergren et al. discusses the core issue of interoperability and its relationship to grid architecture. It provides a detailed framework for developing practical interoperability strategies and ecosystems. In addition, it gives a well-organized mapping of existing interoperability standards and a roadmap methodology to help practitioners develop and execute plans to increase system and organizational interoperability maturity.

Grid architecture and interoperability concepts and principles are apparent in the article “Developing Local Energy Markets: A Holistic System Approach.” This piece by Rassa et al. describes how energy market mechanisms can be applied for coordinating the operation of distribution-level flexibility resources (responsive generation, storage, and load) with reliable system operations. It provides an example of scalable structures for distribution system operations, a coordination platform for integrating distributed energy resources, and a framework for effective interaction between distribution operations and transmission operations.

Muhanji et al. contributed the issue’s last article, “Transforming the Grid’s Architecture: Enterprise Control, the Energy Internet of Things, and Heterofunctional Graph Theory,” which anticipates game-changing impacts to the electric system’s operational frameworks from three types of technology solutions. Enterprise control promises better coordination of technical and economic objectives. The energy Internet of Things envisions connectivity between all things electrical with corresponding integration of processes to bring greater functionality and efficiency to the grid. Meanwhile, heterofunctional graph theory provides tools for this hyperconnected world to study not only complex grid structures but also the tentacles of the electric energy infrastructure as it supports and interacts with water, gas, transportation, and other infrastructures.

The value of grid architecture concepts and tools in facilitating the policy discussions presently underway in our communities and governments is the emphasis of this issue’s “In My View” column by Joseph Paladino. Governments are putting grid architecture to work as they engage with their constituents about the challenges that face the electric system and directions for how to address those challenges. Grid architecture is proving its mettle as a tool to untangle complex issues, point out potential inconsistencies, and provide high-level perspectives on which gains can be made to reach consensus.

We thank all our authors who contributed their time and energy to express their thoughts so eloquently. We are grateful to the IEEE Power & Energy Society and the editor-in-chief of this magazine for the opportunity and support in bringing attention to the discipline of grid architecture.