Guest Editorial: Special Section on Control Centers for the Evolving Power Grid: Architecture and Applications

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THE world-wide drive to decrease greenhouse gases in the atmosphere is rapidly changing the mix of fuel resources that are used to generate electricity. The percentage of fossil fuels, especially coal, is declining while the percentage of renewable resources, like wind and solar, is increasing. The generation mix has always depended on the availability of different fuels in different regions, like the availability of hydro or the acceptability of nuclear power, and the recent changes also depend on this geography, like the radiance of the sun or the intensity of the wind. Although these changes will lead to different architectures in the evolving power grid, some trends are already being felt.

The large central generating stations connected to the transmission network are being replaced with smaller, numerous, non-synchronous, distributed generation sources often connected to the lower-voltage distribution network, or embedded in microgrids that are capable of working in islanded mode. These "edge" devices also include active (dispatchable) loads that are sometimes on the customer side of the meter. This change of the distribution network, from a passive subsystem to a much more controllable and flexible one, is also necessary to increase the resiliency of the grid against more frequent severe weather disturbances as a result of climate change. Increasing resiliency, which is also needed to withstand the threat of cybersecurity, means that in addition to the energy architecture of the grid, the information and communication technology (ICT) architecture of the grid, consisting of monitoring, communication, computation and control that overlays the transmission and distribution, is also changing rapidly.

The large interconnected grids of today, some of which span significant portions of continents, are monitored and controlled, both automatically and by human operators, through a hierarchy of local controls and control centers. The focus of this Special Section is the control center, which is also rapidly evolving to cope with the transformation in the architecture of the power grid both in the energy and the ICT portions. The energy management systems (EMSs) that are responsible for the economic and reliable operation of the bulk power system have new monitoring technologies like phasor measurement unit (PMU) that can support better applications but at the same time losing direct control of energy resources that are increasing on the distribution network. On the other hand, the distribution management systems (DMSs) are now proliferating to monitor and control the distributed energy resources (DERs) which are increasing. In addition to the increasing number of DMS, new applications for the DMS are being designed to handle all the new technologies at the edge of the system. The proliferation of generation and active loads under DMS supervision also increases the coordination needed between EMS and DMS for balancing and other control.

The main objective of this Special Section is to document the present state of the art in control centers and the direction its evolution is taking. We understand that the evolution of the power grid will not be the same all over the world and will certainly not occur at the same rate. Similarly, the evolution of the control centers in the different parts of the world may be different. We asked for manuscripts through a wide call for papers as well as direct requests to authors from certain regions and organizations. We finally selected nine papers in this Special Section that provide glimpses of what is already being tried in control centers today as well as what is being thought about for the control centers in the future. We do not pretend that this coverage in any way is comprehensive but they provide insights into possible "best practices" for the handling of inverter connected distributed renewable resources and active loads like electrical vehicles. Most of all, they provide a look at what control centers will look like when the distribution system, which is much larger than the transmission system, has to be monitored and controlled as closely as the bulk power system.

As mentioned above, all the papers in this Special Section address the evolution of the control center architecture and not the applications used in the control centers. Thus, these papers are quite different from most of the papers on power system operations which focus on real-time power system applications like state estimators, volt-var optimization or outage management and their algorithms. Papers in this Special Section cover the environment in which these applications must reside and how the control center architecture facilitates the running of these old and new applications. They cover the connectivity of the computers within the control center and the connectivity to the grid nodes where the measurements are gathered; they cover how the data is gathered

Manuscript received: March 16, 2022.

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and moved, and the architecture of the communication system that moves the data; they cover the connectivity between control centers whether they be the EMS of neighboring systems or hierarchical between EMS and DMS.

There are two papers that describe the evolving state of the art in distribution management systems, i.e., DMS or ADMS, in China and the western countries: "Integrated Distribution Management System: Architecture, Functions, and Application in China" and "Distribution Control Centers in the US and Europe: Commonalities, Differences, and Lessons". The two papers also reflect the fact that the ownership, standards, and regulations that impact grid operations are quite varied in the US and Europe while they are much more uniform in China.

The rapid increase of distributed renewable energy resources that may be connected to either the transmission or distribution system has raised the question of managing and operating these inflexible and less predictable generation sources. An early concept developed was a separate control center to operate these distributed energy resource management systems (DERMS). The paper "CECRE: Supervision and Control of Spanish Renewable Energies in the Last 15 Years" describes the experience with such a control center. Another paper "Integration of Utility Distributed Energy Resource Management System and Aggregators for Evolving Distribution System Operators" suggests that the concept of DERMS should be merged with other distribution operation functions instead of being separate.

The paper "Architecture, Control, and Implementation of Networked Microgrids for Future Distribution Systems" suggests that the operation of the distribution system can be enhanced by operating various types of microgrids in clusters. The paper "Distribution Management Systems for Smart Grid: Architecture, Work Flows, and Interoperability" presents a more comprehensive architecture where all the applications needed for operating the rapidly evolving distribution grid can exist on the same platform.

The paper "A Review on TSO-DSO Data Exchange, CIM Extensions and Interoperability Aspects" presents a joint-effort in Europe to standardize the communication that will be needed between TSO and DSO to properly coordinate the joint operation of the transmission and distribution systems of the future.

The paper "Architecture, Key Technologies and Applications of Load Dispatching in China Power Grid" presents the concepts evolving in China for using more load control to increase flexibility in the system. The paper "Perspectives of Future Power System Control Centers for Energy Transition" presents a more comprehensive and new approach to the design of the control centers of the future.

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