guest editorial

Luiz Barroso and Hugh Rudnick

the future power system

centralized, distributed, or just integrated?

DISTRIBUTED ENERGY RESOURCES (DERs), including distributed renewable generation, have changed the operational, commercial, and regulatory dynamics of power systems. The growth of DERs has challenged the classic organization of power systems, which was generally based on centralized supply from larger plants, and there has been a broad, worldwide discussion among institutions and agents of the electricity industry about the character of future energy systems in the face of DERs. A fundamental question arises: will the future energy supply be dominated by large-scale power plants, developed by traditional agents and acting in the wholesale market, or by DERs? Some see a DER-dominant future in which millions of proactive energy consumers choose to install DERs behind their electricity meters, revolutionizing the traditional model. Others believe that the future power system will simply be an integrated mix of centralized energy resources and DERs, with most of the traditional model remaining intact.

This discussion is at the core of the reorganization of many power systems worldwide. Many jurisdictions are aggressively pursuing DER penetration for transitioning to a clean-energy system. Many other jurisdictions, on the other hand, have shown less enthusiasm and fewer incentives, which may dictate the pace of DER penetration. They have insisted on centralized generation and questioned the actual costs and benefits of DERs. Even politically, this subject has been explored by slogans, as some places encourage DERs as a kind of democratization of energy, as opposed to the centralized, traditional approach sometimes referred to as a *centralized oligopoly*. Technically, the key challenge is to what extent distributed resources deliver additional value relative to centralized solutions.

There is a stark contrast between today's vision for the future of distributed generation and the current reality. Developing business models that make the vision come true is proving difficult. The lack of existing industry infrastructure, adequate regulations, financing, and consumer interest (which was recently explored in the January/February 2018 issue of *IEEE Power & Energy Magazine*) are just a few reasons why practical applications are confined to niche markets. However, as soon as these barriers are overcome and different resources can participate and compete in markets on the same basis, DERs can go mainstream. Nevertheless, we doubt it can challenge the dominance of centralized generation in the next few decades.

In This Issue

This issue of *IEEE Power & Energy Magazine* presents perspectives about regulatory and industry priorities to facilitate growth of distributed generation while also examining the ability of DERs to compete with and challenge central generation. Authors with experience in both academia and industry who focus on the regulatory and market challenges ahead are featured.

The first article, "Why Distributed?" by Scott P. Burger, Jesse D. Jenkins, Samuel C. Huntington, and Ignacio J. Pérez-Arriaga, opens this issue with a critical review of the tradeoffs between centralized and decentralized resources. The authors' message is quite powerful: to capture the potential value of DERs without incurring substantial social costs, power system planning, policy, and regulation must become more sophisticated with the creation of price signals that clearly present the specific value of temporal and locational benefits. Such price signals would enable an even playing field for competition between centralized and distributed resources, allowing society to maximize social welfare by finding the optimal tradeoff between the economies of unit scale offered by centralized generation and the locational benefits of DERs. The authors conclude that policy support targeted at DERs should be designed in a manner that accounts for these price signals. Where locational value does not outweigh incremental unit costs, regulators and policy makers should carefully consider whether the additional costs of DERs support are justified.

Goran Strbac, Danny Pudjianto, Marko Aunedi, Dimitrios Papadaskalopoulos, Predrag Djapic, Yujian Ye, Roberto Moreira, Hadi Karimi, and Ying Fan make a strong case for DERs to have a very active role in supporting a cost-effective transition to lower-carbon energy systems in "Cost-Effective Decarbonization in a Decentralized Market." The authors

Digital Object Identifier 10.1109/MPE.2018.2884116
Date of publication: 20 March 2019

support their case with studies based on the U.K. power system, which demonstrate that the resulting benefits of a decentralized market supporting distributed flexible technologies are real and significant. Furthermore, this evolution can deliver more competitive electricity markets, reduce the market power of major electricity companies, and enable customer choice-driven system development. These results cannot be fully generalized to other systems, but the conclusions can: appropriate policies and commercial frameworks should be developed in the future to reflect the impact of actions and policies toward DERs, not only on local but also on wider system costs. This requires a fundamentally new market design to recognize the system value of decentralized flexibility, which integrates wholesale and retail markets with location-specific and time-varying energy prices.

The global population lives mainly in megacities, a share that will rise to 70% by 2050, and "Distributed Generation and Megacities," the third article by Vaclav Smil, discusses the DERs' potential to generate significant portions of their energy supply. The article uses the concept of power density to argue that, despite its undoubted advantages, distributed generation is not compatible with every scale and setting. The highly centralized demand of large cities will still require incessant inputs at a multi-gigawatt level in years to come, given by centralized generation. This is a very simple but powerful message.

Lorenzo Kristov complements the first article by diving deeper into the policy landscape that should be in place with DER penetration. In the fourth article "The Bottom-Up (R)Evolution of the Electric Power System," he builds the concept of the integrated-decentralized power system as a compelling vision for the future and discusses the many economic, regulatory, and policy challenges that will emerge. The conclusions support those of the first article, with significant regulatory and pricing challenges that include the need to redefine distribution service, roles, and responsibilities at the transmission-distribution interface and new approaches to cost-benefit analyses. The article concludes by describing how policy makers could enact a few key measures that would pave the way for the integrated-decentralized future.

Next, two articles discuss the role of centralized and decentralized resources in securing new capacity needs and access. "Electrical Expansion in South America," by Rafael Ferreira, Pablo H. Corredor, Hugh Rudnick, Ximena Cifuentes, and Luiz Barroso provides case studies of two emerging countries whose electricity matrices are currently dominated by hydropower, with relatively high long-term energy demand growth rates and where a large portion of the populations currently have limited ability to commit to significant equity disbursements. The common underlying technical, regulatory, and economic factors suggest that centralized and distributed generation expansion are likely to coexist in Brazil

and Colombia over the next decade, with business opportunities in either niche. However, reaching an optimal balance and thoroughly capturing synergies between centralized and distributed generation expansion may require power sector institutions and agents in these countries to change their regulatory, planning, financing, and business models.

The issue closes with "A Pro-Grid Middle Path for Africa," an article by Samuel Oguah and Debabrata Chattopadhyay, which discusses the unique challenges faced in Africa, where additional access to electricity is needed, utilities face difficult financial challenges, and regulations are weak. However, resources are readily available and may include a regional dimension in centralized generation, as the scale of projects requires a demand for electricity that may need to span multiple countries, and distributed generation via microgrids in many regions that today have no electricity or burn liquid fuels. In this context, the authors discuss the tradeoffs between centralized and decentralized supply in Africa from a technical, social, and economic perspective. Although there is a prominent school of thought that electricity supply in African countries can leapfrog from their current state to a largely decentralized system, the authors propose that large, scale-efficient power generation transmission distribution, i.e., a central grid, will be crucial to ending energy poverty. These central systems will also be needed to take advantage of the abundant resources for electricity generation across the continent.

Finally, Paolo Frankl brings his global experience at the International Energy Agency to this debate in his "In My View" contribution. Basing his analysis on factual data, he supports the disruptive character of DERs but reinforces the message that future power systems will be a combination of centralized and decentralized resources, demanding integration and flexibility. He also makes the very relevant point that policy makers and regulators will have a crucial role in the construction of this future, creating the grounds for this integration to happen.

DERs offer new options and tradeoffs for power system planners, policy makers, and regulators and will ensure vibrant and dynamic future power systems. It is clear that centralized generation will still have a significant role in the decades to come and that much regulatory activity is needed to prepare the electricity markets to disclose the costs and benefits of DERs, so that its claimed additional value relative to other supply options becomes clear.

We would like to thank the authors for their time and dedication and the articles they provided, which shed light on key topics related to this relevant discussion. We thank *IEEE Power & Energy Magazine* for the opportunity to reflect on and analyze such challenging matters, which have taken us out of our comfort zones. A special thank you goes to Editor-in-Chief Michael Henderson for continuing to maintain *IEEE Power & Energy Magazine* as an IEEE flagship publication.