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EDITED AND REVIEWED BY
Tarlochan S. Sidhu,
Ontario Tech University, Canada

*CORRESPONDENCE
Nikos Hatziargyriou
nh@power.ece.ntua.gr

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Frontiers in Smart Grids

Nikos Hatziargyriou*

School of Electrical and Computer Engineering, National Technical University of Athens, Athens, Greece

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Increasing concerns about climate change, the security of supply and economic affordability dictate the needs for a drastic evolution in the ways energy is produced, transported, and used (European Commission, 2018). These needs drive the on-going transition of the energy systems all over the world, characterized by a fast-changing energy generation mix with a clear tendency toward renewable and distributed energy resources, including distributed generators, flexible loads, distributed storage units, electric vehicles, etc. It also includes new market models favoring active participation of consumers in shaping their energy profiles and their transformation to energy prosumers, individually or organized in energy communities. The operation of such a complicated system requires the "smartening" of networks with high degrees of decentralized control and operation automation, aided by the admirable advances in information and communication technologies (ICT). Smart Grids are defined as the Energy Networks that satisfy the needs of all their users, be it consumers, producers and prosumers in an efficient and sustainable way [(European Technology Platform (ETP) Smart Grids, 2006)].

The transition of the energy system involves the shift from a centralized model with few large, mostly thermal units and unidirectional energy flows from generation through transmission and distribution to a more decentralized system with many distributed energy resources at all voltage levels and bidirectional energy flows. The most drastic changes happen at the ex-passive distribution networks, that have now to accommodate increased shares of Renewable Distributed Energy Resources (DER), thus becoming active distribution systems. It is characteristic that the large majority of RES units, mostly solar and wind, are connected at the Low Voltage and Medium Voltage distribution networks (in the range of 70–90%). The penetration of a large number of DER at the distribution networks provokes several challenges in the power system operation, like reverse power flows, voltage rises at remote buses in radial distribution networks, but also a*dditional power flows in the transmission system, significant variations in transmission capacity use and transmission congestion* during high energy dispatch periods. Moreover, DER have significant impacts on the dynamic operation of the power system. In particular, the reduced inertia caused by the replacement of rotating masses of large synchronous generators by power electronics interfaced DER will have an inevitable i*mpact on Grid stability (frequency and voltage), although not always negative.*

The "smartening" of distribution networks requires effective ways of control of the various interconnected DER by exploiting the capabilities offered by the power electronic converters. The application of Grid forming inverters to support the grid and new network technologies, like D-FACTS, smart transformers, etc. offer very promising capabilities for a more efficient and secure operation. Moreover, highly flexible, distributed architectures that distribute the operation responsibility in lower voltage levels or even in grid components themselves, able to make autonomous decisions, appear as viable alternatives (Hatziargyriou, 2014). Microgrids, which form parts of the distribution network interconnected to the upper grid at a point of common coupling, but also capable to operate islanded, in case of faults in the upstream network provide such novel operation paradigms. Currently, microgrids are considered as key components in power system decentralization, providing viable solutions for rural electrification, supporting local energy communities and enhancing resilience and system operation. Their main characteristic is the coordinated control of the interconnected distributed energy resources (DER), which can be realized by various methods, ranging from decentralized communicationfree approaches to centralized ones, where decisions are taken at a central point. DC and hybrid AC/DC networks provide further possibilities for increasing operational efficiency.

The high penetration of intermittent and variable RES requires the provision of sufficient flexibility to balance their stochastic behavior together with demand (Mohandes et al., 2019). As dispatchable thermal units, that have traditionally provided the necessary flexibility, are gradually withdrawn from the system, flexibility sources available at the distribution level in the form of distributed generators, active consumers, distributed storage and EV smart charging stations need to be exploited. The activation of flexibility services will influence grid operation of the whole power system and should be used efficiently from both technical and economical point of view requiring a well-coordinated process between TSOs and DSOs, including market parties. Crucial flexibility can be also provided by coupling various energy sectors, i.e., electricity, natural gas (biogas) and hydrogen, heating and cooling, liquid fuels, transport, etc. Planning and operation of combined energy carrier networks interfaced by their conversion devices and storage (electrical, thermal, mechanical, gas and liquid) provide a holistic consideration of the energy system with the electricity networks forming the backbone due to their high versatility and efficiency.

Another major challenge of current power system is posed by extreme weather events, earthquakes, floods, and wildfires that have resulted in major power disruptions around the world, lasting from few hours to few weeks. Resilience has been defined as the grid's ability to withstand extraordinary and high-impact low-probability events, that may have never been experienced before, rapidly recover from such disruptive events, and adapt its operation and structure to prevent or mitigate the impact of similar events in the future. The application of "smart" operational measures, i.e., intelligent control that aims to face the events while they progress by adapting the system's operation Infrastructure together with effective hardening measures aiming to make the system assets less vulnerable to extreme events are key concerns of today's energy systems (Panteli et al., 2017).

The challenges for planning and operation of such a complicated system requires reliable and structured data. Today, there are abundant data available to system operators coming from extended networks of PMUs, sensors, microprocessors and smart meters installed throughout their networks. These data can provide new digital services and business opportunities for all stakeholders in the energy market for activities related to load management, storage, smart charging of electric vehicles, energy efficiency in the industrial and domestic sector, emergence of prosumers, smart cities and energy communities, etc. They can be used to create open data platforms to provide access to information and transparency to all stakeholders. For system operators in particular, data exploitation can lead to drastic improvement of services to customers, reduction of operating costs, investment deferral for network upgrades, self-healing by fast fault isolation and recovery after disturbances, predictive maintenance for efficient asset management, etc. The application of Artificial Intelligence together with technologies for handling large amounts of data (Big Data) and Internet of Things (IoT), provide new opportunities for customer participation in local energy markets, "smart" network management and effective integration of distributed energy resources. The ultimate goal is the automatic, uninterrupted satisfaction of all energy needs at the right time, right place and lowest possible cost.

Frontiers in Smart Grids will provide an open platform welcoming high impact publications addressing the above challenges. Its specialty sections will cover a broad research spectrum including basic research and development of practical applications of Smart Grids technologies. Our journal will include regular research papers and review articles essential for education in the field of Smart Grids.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

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