Guest Editorial: Special Section on Smart DC Distribution Systems

WITH RAPID development of power electronics systems, development of modern control paradigms, and direct-current (dc) nature of most renewable energy sources, emerging electronics loads and storage units, dc microgrids and distribution systems are becoming a viable alternative as they perform better in terms of efficiency, scalability, and stability.

By observing the residential energy consumption pattern, we may discover that major part of our consumption loads are becoming more and more dc, e.g., laptops, cellphones, LED lights, displays, etc. Therefore, why the electric grid is conceived in ac? Main reason is that the grid is designed to support conventional loads for more than a century, basically induction motors and other ac appliances. Furthermore, to transmit electricity with minimum losses, we have to increase the voltage to reduce the current, which was previously only possible by using ac transformers. After one century, the contemporary residential loads have been changed a lot, but the electric grid practically stayed intact. This implies that every time we plug-in one of these new loads to the grid, a conversion stage from ac to dc is indispensable. You can easily notice the huge losses of this conversion process from the dissipated heat at the transformer of your laptop. On the other hand, generation also changed from big synchronous generators connected to nuclear, coil, or hydropower plants to small solar panels, fuel cells, or batteries, which are essentially dc sources. Even small-scale wind or gas turbines are more efficient by using only one converter (ac/dc) instead of two back-to-back converters (ac/dc and dc/ac). Such unnecessary conversion stages can contribute to up to 15–20% of total losses. This will naturally lead to an emerging grid in which microgrids and distribution systems at homes and buildings would be done in dc. With home microgrids, now ac and in the future dc, electrical vehicles will be also playing an important appliance role at home, given the dc nature of onboard storage elements and emerging dc charging stations. It is expected to charge the onboard storage unit at night when the electricity is cheaper.

This revolution can be seen as a "back-to-Edison" phenomenon, which is already happening in high-voltage direct current (HVDC) systems and is becoming a reality in low-voltage and medium-voltage distribution systems. dc microgrids and distribution systems are spreading around the world in different application domains, e.g., dc data centers, dc homes, dc buildings and offices, medium-voltage distribution systems in electric ships, and so on. In the view of this rapid establishment and adaptation of dc paradigms in the distribution level of the future smart grid, the objective of this Special Issue is to disseminate state-of-the-art research and development results on "Smart DC Distribution Systems." As a result, 19 papers have been selected and organized into the following topics:

1) control of dc microgrids;
2) stability assessment and remedies for dc distribution systems;
3) low voltage dc distribution utility sites;
4) protection issues in dc distribution networks;
5) optimization, energy management, and demand response paradigms.

These topics and their papers are explained in the following Sections.

I. Control of DC Microgrids

In this section, five papers deal with advanced control issues for dc microgrids, including droop control, virtual impedances, fuzzy logic, neural networks, adaptive control, and hierarchical control.

"Intelligent Distributed Generation and Storage Units for DC Microgrids—A New Concept on Cooperative Control Without Communications Beyond Droop Control" by N. Diaz *et al.*, proposes a decentralized strategy based on fuzzy logic that ensures stored energy balancing for low voltage dc microgrids with distributed battery energy storage systems. The control mechanism consists on modifying the virtual resistances of the droop controllers in accordance with the state of charge of each energy storage unit.

"An Intelligent Control System Used to Improve Energy Production From Alternative Sources With DC/DC Integration" by R. Bastos *et al.*, presents a fuzzy controller for charging/discharging of a battery pack connected to a photovoltaic (PV) forming a dc microgrid with ac grid connection capabilities.

"Decentralized Discrete-Time Adaptive Neural Network Control of Interconnected DC Distribution System" by S. Kazemlou *et al.*, enhances the stability of a dc distribution system by using a decentralized adaptive nonlinear controller that employs neural networks to mitigate voltage and power oscillations after disturbances. The adaptive controller is introduced to overcome the unknown dynamics of each converter and to stabilize the dc grid by using only local measurements.

"Optimal, Nonlinear, and Distributed Designs of Droop Controls for DC Microgrids" by Z. Qu *et al.*, presents a cooperative droop control that is robust with respect to uncertain changes in both distribution network and

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sensing/communication network. The control is an effective scheme for operating dc microgrids with intermittent and distributed generation.

"DC Microgrids: Economic Operation and Enhancement of Resilience by Hierarchical Control" by L. Che *et al.*, discusses the possibilities and the merits of adopting a dc control system to enhance the economics and the resilient operation of a dc microgrid, and to test the proposed hierarchical control strategy for a dc microgrid.

II. Stability Assessment and Remedies for dc Distribution Systems

This section includes five papers about stability analysis and enhancement for dc distribution systems and islanded microgrids. Emerging applications of dc distribution systems in safety- or mission-critical application domains such as electric ships or electric vehicles chargers demand tools and techniques for stability assessment and improvement. Distribution systems with constant power loads are of particular interest.

"Stability Assessment of a DC Distribution Network in a Hybrid Micro-Grid Application" by P. Shamsi *et al.*, studies the stability of a dc distribution network in an ac/dc hybrid micro-grid. The extended averaging method of the dc distribution network is developed and the stability assessment is performed by using the pole-zero analysis.

"Degree of Influence of System States Transition on the Stability of a DC Microgrid" by S. Sanchez *et al.*, presents a methodology that takes into account the structure of a dc microgrid system to evaluate its stability. The stability analysis and real-time simulation results present the grid behavior and validate the operation limits.

"Multiconverter Medium Voltage DC Power Systems on Ships: Constant-Power Loads Instability Solution Using Linearization via State Feedback Control" by G. Sulligoi *et al.*, studies the bus voltage stability in medium-voltage dc power systems on ships in the presence of constant power loads that may induce voltage instabilities.

"Improving the Performance of a Line Regulating Converter in a Converter-dominated DC Microgrid System" by R. Ahmadi *et al.*, describes the controller design procedure for a line-regulating converter in a converter-dominated dc microgrid system. The purpose of the controller is to mitigate the effects of the constant power loads on the stability and performance of the dc microgrid system.

"Stability of a DC Distribution System for Power System Integration of Plug-In Hybrid Electric Vehicles" by M. Tabari *et al.*, proposes a method for enhancing the stability of a dc distribution system that integrates plug-in hybrid electric vehicles with an ac power grid. The dc distribution system is interfaced with the host ac grid via a voltage-sourced converter which can also embed PV modules.

III. Low Voltage dc Distribution Utility Sites

In this section, three papers from a real low voltage dc distribution site are presented, including practical solutions design, and implementation.

"Research Site for Low-Voltage Direct Current Distribution in a Utility Network—Structure, Functions, and Operation" by P. Nuutinen *et al.*, introduces a research site for a low voltage dc distribution system. The research site was established to enable practical studies concerning different areas of the low voltage direct current (LVDC) distribution and microgrids.

"On Common-Mode and RF EMI in a Low-Voltage DC Distribution Network" by P. Nuutinen *et al.*, addresses common-mode and radio frequency electromagnetic interferences in a converter-fed low-voltage direct current distribution research network. Radio frequency disturbances are measured and analyzed in a real dc network site using power line carrier (PLC) communication.

"Galvanic Isolation and Output LC Filter Design for the Low-Voltage DC Customer-End Inverter" by A. Mattsson *et al.*, introduces the design of the galvanic isolation and output filter inductor in the customer-end inverter of a low voltage dc network. Cost effectiveness and lifetime are considered in the proposed design approach.

IV. Protection Issues in dc Distribution Networks

New protection devices and systems are required for low-voltage dc distribution systems. In this section, two papers are devoted to the protection issues in dc systems.

"An Advanced Protection Scheme for Enabling an LVDC Last Mile Distribution Network" by A. Emhemed *et al.*, presents an advanced protection scheme that addresses the challenges of protecting an LVDC distribution network. The scheme takes advantage of local measurements and communications that will be integrated in smart grids, and the excellent level of controllability of solid-state circuit breakers.

"High-Speed Differential Protection for Smart DC Distribution Systems" by S. Fletcher *et al.*, proposes a high speed current differential implementation approach for smart dc distribution systems capable of sub-millisecond fault detection. The implementation approach can consistently and promptly achieve protection of the system operating within the order of a few microseconds.

V. Optimization, Energy Management, and Demand Response Paradigms

In order to optimize the configuration and operation of the dc distribution system, demand side management systems, and energy management systems are necessary. This section includes four papers dealing with these issues in dc microgrids for residential clusters, buildings, and communities.

"Dynamic Partitioning of DC Microgrid in Resilient Clusters Using Event-Driven Approach" by M. Simonov, presents a dynamically reconfigurable system with cognitive intelligence that is capable of assessing the grid resiliency and to rebuild more resilient grid partitions. The algorithm, which was originally designed for ac and then translated to the dc case, performs automated actions across the neighborhood. The proposed tool helps assessing dc microgrids with high penetration of renewable energy.

"Towards Building an Optimal Demand Response Framework for DC Distribution Networks" by A.-H. Mohsenian-Rad *et al.*, designs a demand response algorithm for dc distribution networks. The approach is based on adjusting the internal parameters of flexible power electronics loads to ensure reliable and efficient operation of the dc distribution system.

"Multi-Objective Optimization and Design of Photovoltaic-Wind Hybrid System for Community Smart DC Microgrid" by M. Shadmand *et al.*, presents an optimization technique based on a multiobjective genetic algorithm, which employs a techno-economic approach to determine the system design optimized by considering multiple criteria including size, cost, and availability. The result is the baseline system cost necessary to meet the load requirements that can also be used to monetize ancillary services that the smart dc microgrid can provide to the utility grid, such as the voltage regulation.

"Energy Management DC System Based on Current-Controlled Buck-Boost Modules" by H. Ramirez *et al.*, presents the guidelines of a series hybrid fuel cell system, including control and protection loops. This dc system consists of a fuel cell, an auxiliary storage device, and current-controlled dc–dc converters responsible for managing the energy transfer between the generation/storage elements and the loads.

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