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Guest Editorial: Special Section on Smart DC Distribution Systems

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Guest Editorial Special Section on Smart DC Distribution Systems

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

Just taking a look on how our electricity system is at home, we may discover that major parts of our consumption loads are becoming more and more DC, e.g. laptops, cellphones, LED lights, displays, etc. So, why electrical grid is conceived in AC? Main reason is that the grid is designed to support loads for more than one century, basically induction motors and other AC appliances. Furthermore, in order to transport electricity with minimum losses, we have to increase the voltage to reduce the current, which was only possible by using AC transformers. After one century, the loads at home have been inherently changed a lot, but not the electrical grid. This means that every time we plug-in one of these new loads to the grid, it is necessary to convert from AC to DC. 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 is also changing from big synchronous generators connected to nuclear, coal, or hydropower plants to small solar panels, fuel cells, or batteries, which are essentially DC sources, even small wind or gas turbines are more efficient by using only one converter (AC/DC) instead of two (AC/DC and DC/AC). This is pointing out a next future 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. It is expected that during the night, when the electricity is cheaper, the electrical vehicle energy storage may be charging, i.e. filling the battery set and/or generating hydrogen for the fuel cell system.

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 DC distribution systems are spreading around the world with many different applications: DC data centers, DC homes, DC buildings and offices, DC ships, and so on. In the view of this rapid establishment of DC in the distribution level of the future smart grid, the objective of this Special Section is to disseminate state-of-the-art research and

development results on "Smart DC Distribution Systems". As a result, nineteen papers have been selected and organized into the following topics:

- 1) Control of DC microgrids
- 2) Stability analysis and solutions for DC distribution systems
- 3) Low voltage DC distribution utility site
- 4) Protections for DC distribution networks
- 5) Optimization, energy management and demand response

These topics and the papers included are explained in the following sections of this Guest Editorial.

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.

- 1) "Intelligent Distributed Generation and Storage Units for DC Microgrids - A New Concept on Cooperative Control without Communications Beyond Droop Control" by N. Aldana, 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 of modifying the virtual resistances of droop controllers in accordance with the state of charge of each energy storage unit.
- 2) "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.
- 3) "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.
- 4) "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 sensing/communication network. The control is an effective scheme for operating DC microgrids with intermittent and distributed generation.
- 5) "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 for enhancing the economics and the resilient operation of a DC microgrid, and to test the proposed hierarchical control strategy that applies to a DC microgrid.

II. STABILITY ANALYSIS AND SOLUTIONS FOR DC DISTRIBUTION SYSTEMS

This section includes five papers about stability analysis and enhancement for DC distribution systems and islanded microgrids. New applications such as DC grid ships or DC distribution systems connected to electrical vehicles need for stability assessment and improvement. Special attention is rising in DC systems that include constant power loads due to the instability issues.

- 1) “Stability Assessment of a DC Distribution Network in a Hybrid Micro-grid Application” by P. Shamsi et al., studies the stability analysis 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 pole-zero analysis.
- 2) “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 and evaluates its stability. The stability analysis and real time simulation results present the grid behavior and validate the limits of operation.
- 3) “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 with the presence of constant power loads that may induce voltage instabilities.
- 4) “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.
- 5) “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 photovoltaic modules.

III. LOW VOLTAGE DC DISTRIBUTION UTILITY SITE

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

- 1) “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 LVDC distribution and microgrids.

- 2) “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 DC distribution research network. Radio frequency disturbances are measured and analyzed in a real DC network site when using power line carrier (PLC) communication.
- 3) “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. PROTECTIONS FOR DC DISTRIBUTION NETWORKS

In low voltage DC distribution systems, new protection devices and systems are required. In this section, two papers are devoted to DC systems protection.

- 1) “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 for protecting an LVDC distribution network. The scheme takes advantage of advanced local measurements and communications that will be integrated in smart grids, and the excellent level of controllability of solid state circuit breakers.
- 2) “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 achieve protection of the system operation within the order of a few microseconds.

V. OPTIMIZATION, ENERGY MANAGEMENT AND DEMAND RESPONSE

In order to optimize the configuration and operation of the DC distribution grid, 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.

- 1) “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 to assess the resilience of and to re-build better resilient grid partitions. The algorithm, which was originally designed for AC and translated to the DC case, lets perform automated actions across the neighborhood. The proposed tool helps assessing DC microgrids with a high penetration of renewable energy.
- 2) “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 power electronics loads to ensure reliable and efficient operation of the DC distribution system.

- 3) "Multi-Objective Optimization and Design of Photovoltaic-Wind Hybrid System for Community Smart DC Microgrid" by M. Shadmand et al., devises an optimization technique based on a multi-objective 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 and can also be used to monetize ancillary services that the smart DC microgrid can provide to the utility grid, such as voltage regulation.
- 4) "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 the 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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