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Editorial

Recent Trends in DC and Hybrid Microgrids: Opportunities from Renewables Sources, Battery Energy Storages and Bi-Directional Converters

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Featured Application: Hybrid microgrids for residential applications with connections to renewable energy sources, electric vehicle recharging stations and the AC energy grid.

Abstract: This editorial manuscript reviews the papers accepted for publication in the Special Issue "DC & Hybrid Microgrids" of *Applied Sciences*. This Special Issue, co-organized by the University of Pisa, Italy and Østfold University College in Norway, has collected nine papers from 25 submitted, with authors from Asia, North America and Europe. The published articles provide an overview of the most recent research advances in direct current (DC) and hybrid microgrids, exploiting the opportunities offered by the use of renewable energy sources, battery energy storage systems, power converters, innovative control and energy management strategies.

Keywords: microgrid; direct current (DC) grid; hybrid microgrid; smart grid; battery energy storage; renewable energy sources (RES); hybrid vehicles (HEV); full-electric vehicles (EV); bidirectional converters

1. Introduction

This editorial analyzes the manuscripts accepted, after a careful peer-reviewed process, for the Special Issue "DC & Hybrid Microgrids" of *Applied Sciences*. The Special Issue has been co-organized by the University of Pisa (Full Professors Sergio Saponara and Roberto Saletti at the Department of Information Engineering), Italy and Østfold University College (Full Professor Lucina Mihet-Popa at the School of Engineering) in Norway.

The nine accepted manuscripts were co-authored by research groups from three continents, consisting of authors from Norway, Denmark, Italy in Europe; India, China, Japan, Vietnam in Asia; and the USA in North America.

As reported in Section 2 of this editorial, the selected papers give an overview of the trends in research and development activities about direct current (DC) and hybrid microgrids. By exploiting the opportunities offered by the use of renewable energy sources, battery energy storage systems, power converters, and innovative control and energy management strategies, new scenarios are opened with the opportunity for industrial exploitation.

2. Recent Trends in DC & Hybrid Microgrids

The Special Issue is characterized by eight original research papers [1–8] and one review paper [9].

The first paper [1] entitled "Research on Virtual Inductive Control Strategy for Direct Current Microgrid with Constant Power Loads", was written by Zhiping Cheng et al., authors from the School of Electrical Engineering, Zhengzhou University, China. Aiming at improving the stability of DC microgrids with constant power loads, the paper presents a novel virtual inductive approach. Indeed, it is known that the negative impedance characteristic of constant power loads will lead to DC bus voltage fluctuations. A simplified circuit model of the system has been obtained for the analysis by modeling the distributed resources. Unlike the existing control strategies, the proposed controller constructs a negative inductance link which helps to counteract the negative effects of the line inductive between the power source and the transmission line. Detailed performance comparisons of the proposed control and virtual capacitance are carried out by means of MATLAB/Simulink simulations. The improved performance of the proposed control strategy has been further validated with several detailed studies and the achieved results demonstrate the feasibility of the proposed approach.

The second paper [2], entitled "Improvement of an Islanding Detection Method Based on the Perturbation Signal in Case of a Multi-Photovoltaic Operation", is by Thanh Son Tran et al., from the Graduate School of Engineering and Science and the Department of Electrical Engineering, Shibaura Institute of Technology, Tokyo, Japan and the Department of Power System, Hanoi University of Science and Technology, Hanoi, Vietnam. The paper deals with the issues of the islanding phenomenon, which is one of the consequences of the emergence and development of microgrids in the power system. A common problem of a multi-distributed generation (particularly when using multiple renewable energy sources, such as the multi-photovoltaic sources addressed in this paper) is the cancellation of the injected signals, which has a significant influence on active islanding detection methods. This paper analyzes this issue by injecting a perturbation signal in a multi-photovoltaic system. A promising solution for the injected signal cancellation was also proposed in the manuscript and validated through mathematical explanations and simulations.

The third paper [3], entitled "Insulation Monitoring Method for DC Systems with Ground Capacitance in Electric Vehicles", was written by Jifei Du et al., from the School of Electrical Engineering, Beijing Jiaotong University, and the National Active Distribution Network Technology Research Center (NANTEC), Beijing Jiaotong University. The paper deals with the issue of the influence of ground capacitance in electric vehicles, so that the voltage of positive and negative electric bridges changes slowly in the traditional unbalanced electric bridge DC insulation monitoring (DC-IM) method. Sampling should be conducted once the voltage of the bridge becomes stable, to calculate the insulation resistances. This fact will inevitably extend the monitoring cycle. The paper proposes a three-point climbing algorithm to reduce the monitoring cycle. The algorithm consists in a three-bridge voltage sampling with equal sampling intervals, to predict the evolution of the bridge voltage curve. The insulation resistances calculated by sampling values will deviate from the actual values because of the presence of sampling errors. The paper also proposes a filter and a correction method to solve this issue. Experimental data are reported to show the influence of different parameters on the results and to make a comparison with the traditional method. When compared to the state of the art, the proposed technique can monitor insulation resistance more quickly and can ensure fixed monitoring cycles under different ground capacitance values, while keeping a similar monitoring accuracy.

The fourth paper [4], entitled "Improved Control of Forest Microgrids with Hybrid Complementary Energy Storage", by Ming Yu et al. is also from China, particularly from the School of Technology, Beijing Forestry University. The paper proposes a hybrid complementary energy storage control method to improve the power quality and the fault ride-through capability of islanded forest microgrids. In the paper, mode-based sectional coordinated control is adopted as the basic control scheme, whereas control of the hybrid energy storage adopts the improved strategy. The hybrid energy storage system contains a battery and a supercapacitor coupled to a wind turbine subsystem. Given the different characteristics of the energy storage units, the adaptive control of battery and supercapacitor are adopted in the paper to smooth the low-frequency power fluctuation in the long term and to suppress the high-frequency component separately. It is to be noted that a predictive control of the converters is adopted to achieve rapid regulation. The wind power unit is also investigated as third energy storage unit. The idea involves utilizing the large rotating kinetic energy of the wind turbine to temporary suppress huge power disturbances and to avoid load shedding. The paper show simulations of the islanded DC microgrid in forest areas, performed with MATLAB/Simulink, to validate the effectiveness of the proposed coordination control with hybrid complementary energy storage. The achieved results show that the transient operation characteristics of the system were effectively enhanced by utilizing the improved control method.

The fifth paper [5], entitled "An AC/DC Distribution Network DG Planning Problem: A Genetic-Ant Colony Hybrid Algorithm Approach", is by Deyang Yin et al. from the School of Electrical Engineering, Southeast University, Nanjing, China and the College of Energy and Electrical Engineering, Hohai University, Nanjing, China. The paper addresses the topic of the planning problem of distributed generators (DG) accessing the AC/DC distribution network. The paper presents a location and volume model of a DG that considers several DG costs, such as operation and maintenance costs, investment costs, system network loss costs, fuel costs, pollution compensation costs, and environmental protection subsidies. Voltage and power constraints are also considered in the model. A hybrid algorithm that combines the ant colony algorithm (ACO) and the genetic algorithm (GA) is proposed to solve the model presented, resulting in a GA-ACO technique. The IEEE-33 node distribution network is taken as example to verify the rationale of the proposed approach and its effectiveness. The simulation results show that the proposed model is aligned with reality and the hybrid algorithm is effective in solving the model, with advantages in both convergence speed and convergence results, if compared to single ACO and/or GA techniques.

The sixth paper [6], entitled "A Stability Preserving Criterion for the Management of DC Microgrids Supplied by a Floating Bus", by D. Bosich et al. is from Italy, from the Department of Engineering and Architecture, University of Trieste and the Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano in Milan. One of the most important enabling technologies for the future development of microgrids is DC distribution. This is due to the easier interfacing with many DC components of a modern smart grid, such as batteries, photovoltaic systems, and native DC loads. The large use of controlled power converters suggests the need for a careful analysis of system stability in these power systems, as the stability can be impaired in particular conditions. For example, a destabilizing effect can arise in DC power systems due to the presence of inductor/capacitor (LC) filtering stages installed for power quality requirements. Other stability problems can arise due to high-bandwidth controlled converters that behave as constant power loads (CPLs). This issue is even more critical when the CPL is potentially fed only by the battery, causing the DC bus to float. A valuable method for studying the system stability of DC microgrids feeding CPLs is the Lyapunov theory, which demonstrates how the region of asymptotic stability (RAS) shrinks, as the state of charge of the battery diminishes and the bus voltage decreases. Once the accuracy of the RAS is validated by comparing it to the real basin of attraction (BA) and numerically derived using continuation methods, a smart power management of the CPL is proposed in the paper to preserve the system stability, even in presence of a low bus voltage. As discussed in the paper, a suitably designed criterion for limiting the load power can guarantee the invariance of RAS and BA for each equilibrium point. An electric vehicle was also used in the paper as particular DC microgrid component for evaluating the performance derating given by the power limitation.

The seventh paper [7], entitled "Multidimensional Optimal Droop Control for DC Microgrids in Military Applications", is by K. J. Bunker at al. from the USA, from the Department of Electrical and Computer Engineering, Michigan Technological University in Houghton; the Rocky Mountain Institute, Boulder; and the Department of Mechanical Engineering and Engineering Mechanics, Michigan Technological University. The paper deals with reliability issues of microgrids when they are used for defense applications. Droop control provides a simple option without requiring communication between microgrid components, increasing the control system reliability. As discussed in the paper, traditional droop control does not allow the microgrid to utilize much of the power available from solar renewable sources, such as a photovoltaic resource. The paper shows the application of an optimal multidimensional droop control strategy for a solar resource connected in a microgrid at a military patrol base to solve this issue. The paper reports simulation and hardware-in-the-loop experiments of a proof-of-concept microgrid to show that much more power from the solar resource can be utilized, while maintaining the system's bus voltage around a nominal value, and still avoiding the need for communication between the various components.

The last original research paper of the special issue [8], entitled "Energy Management Strategy for Rural Communities' DC Micro Grid Power System Structure with Maximum Penetration of Renewable Energy Sources", written by M. Gunasekaran et al., it is a collaborative work by three research groups from the Department of Electrical and Electronics Engineering, SRM University, Chennai, India; the Faculty of Engineering, Østfold University College, Norway; and the Department of Energy Technology, Aalborg University, Denmark. Regarding classic AC grid with power distribution to many DC loads, DC microgrids are suitable to provide high efficiency, consistency, reliability, and load sharing performance, particularly when interconnected to DC renewable and storage sources. The main control objective for any DC microgrid is providing proper load–power balancing based on the distributed generator sources. Due to the intermittent nature of renewable energy sources, batteries play an important role in load–power balancing in a DC microgrid. State-of-the-art energy management strategies may be able to meet the load demand, but often such techniques are not suitable for rural communities. To solve this issue, the paper proposes an energy management strategy (EMS) for a DC microgrid to supply power to rural communities with solar, wind, fuel cell, and batteries as input sources. The proposed EMS performs the load–power balancing between each source (renewable and storage) in a DC microgrid for dynamic load variations. The EMS proposed in the paper, which manages two battery sources, is capable of achieving load–power balancing using renewable energy sources with less consumption than non-conventional energy sources such as a diesel generator. The performance of the system is analyzed based on the different operating conditions of the input sources and verified by means of both simulation models and a laboratory real-time DC microgrid experimental setup.

Finally, the review paper [9], entitled "Hybrid Microgrids Exploiting Renewables Sources, Battery Energy Storages, and Bi-Directional Converters", is co-authored by the Special Issue guest editors from University of Pisa, Italy and Østfold University College, Norway. With reference to a new and improved energy grid, the guest editors' review paper analyzes trends in renewable energy sources, power converters, and control strategies, as well as battery energy storage technologies and the relevant issues in battery charging and monitoring. The paper also proposes an alternative microgrid architecture overcoming the lack of flexibility of the classic energy grid. By mixing DC and AC sources, the proposed hybrid microgrid stands as an alternative solution where the use of bidirectional electric vehicle chargers creates a microgrid that directly interconnects all the partner nodes with bi-directional energy flows. This model is further sustained by the new products emerging in the market, since new solar inverters are appearing in which a local energy storage system for the renewable energy sources is available. Therefore, the power flow from/towards the renewable energy sources becomes bidirectional, with improved flexibility and efficiency.

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