Power electronics in renewable energy systems

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Editorial

Power Electronics in Renewable Energy Systems

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1. Introduction

Renewable energy-based generation of electrical energy is currently experiencing rapid growth in electrical grids. The dynamics of electrical grids are starting to change due to the large-scale integration of power electronic converters into the grid for facilitating the utilization of renewable energy. The main problem with the use of grid-connected power electronic converters is the negative incremental resistor behavior observed in their input and output terminal impedances, which makes the grid prone to harmonic stability problems that are observed nowadays more and more often. This problem is difficult or even impossible to remove because the converters have to be synchronized to the grid frequency, which actually creates the named output terminal-related problematic behavior. The input terminal-related problem is usually related to the output terminal feedback arrangement or to the grid synchronization actions. There are naturally many other problems, which can be related to the application of the renewable energy sources as an input source of the converters, and which can change their dynamic behavior profoundly.

The Special Issue of Energies "Power Electronics in Renewable Energy Systems" was intended to disseminate new promising methods to tackle the stability problems observed to take place in power grids, and to provide new information to support the understanding of the origin of those problems. The particular topics of interest in the original call for papers included, but were not limited to:

- Stability and modeling of large grid-connected PV and wind power plants;
- Dynamic modeling and control design of renewable energy converters in grid feeding, supporting, and forming modes;
- Impedance-based grid interaction studies;
- Issues related to control, stability, diagnostics and interfacing of energy storage in renewable energy systems;
- Voltage and frequency control of grids with high penetration of renewable distributed generation.

This special issue of Energies contains four invited submissions [1–4], three review articles [5–7], and twenty-three research articles [8–30] covering different topics in renewable energy systems. The authors' geographical distribution is:

China (14); Finland (4); Korea (2); The Netherlands (1), Japan (1); Israel (1); USA (1); Canada (1); India (1); Jordan (1); Malaysia (1); Italy (1); UK (1).

We thank the editorial staff and reviewers for their great efforts and help during the process.

2. Brief Overview of the Contributions to This Special Issue

The main contributions of the paper are briefly reviewed in the following subsections. The first subsection reviews the invited papers, the second subsection reviews the review papers, and the third subsection reviews the article-type papers that are not reviewed in first subsection. No topic-specific classification is applied.

2.1. Invited Papers

Suntio et al. [1] introduce the full picture of the source and load interaction formulations covering typical three-phase grid connected inverters, which are applied in renewable energy applications. The complexity of the analyses is obvious. The paper contains both simulated and experimental evidence to support the theoretical findings in the paper. It is clearly demonstrated that omitting the cross-coupling elements in the associated impedances will lead to very poor accuracy of the interaction analyses. Messo et al. [2] demonstrate that it is possible to implement an emulator for a grid-connected three-phase inverter by applying a high-bandwidth amplifier, which can be used effectively to study the dynamic behavior of AC microgrids. Sun et al. [3] study the behavior of the phase locked loop (PLL) of the grid-connected power converter during a phenomenon known as rate of change of frequency (ROCOF) and its influence on the stability of the grid. Such a phenomenon has been observed to take place in the Bonaire Island power grid as a consequence of a grid fault. According to the study, the PLL control bandwidth has a crucial role in the well-being of the power grid. Amer et al. [4] studied the maximum power point (MPP) tracking process, where the perturbation frequency was adaptive instead of the step size to ensure a fast and trouble-free tracking process. The demonstrations show that the proposed technique works well.

2.2. Review Papers

One of the review papers [1] was already reviewed in Section 2.1. Suntio [5] introduces the small-signal modeling and analysis of a peak-current-mode (PCM) controlled buck converter, which operates in discontinuous conduction mode (DCM). The modeling method is introduced already in 2001 but the given models are load-resistor affected and do not contain the effect of circuit parasitic elements. The paper shows that the load resistor hides the real location of the unstable pole, which is usually assumed to appear at the output–input voltage ratio of 2/3, but it can appear at the output–input voltage ratio of 1/2. It is also observed that the circuit elements have a significant contribution to the dynamic behavior as well. Tareen et al. [6] compare the use of static compensator (STATCOM) and active power filter (APF) in tackling the power quality issues in the case of high penetration of renewable energy sources in the power grid. The paper provides a comprehensive survey of the related topics and a wide list of key finds, which cannot be presented briefly in this overview.

2.3. Article Papers

Wang et al. [7] proposes a modified self-synchronized synchronverter, which works better in an unbalanced grid compared to the conventional self-synchronized synchronverters. The main benefit of the synchronverters is that there is no need for PLL function, which would eliminate the negative incremental resistor phenomenon in the output impedance of the grid-connected converter. Rizqiawan et al. [8] introduce the development of grid-connected inverter modules intended for teaching microgrid issues to electrical engineering students. Liu et al. [9] introduce issues related to the concept known as Energy Internet, where microgrid control is implemented based on the internet by utilizing the concept of an energy router. In this study, the primary energy sources are considered to be a photovoltaic array, an energy storage battery, and the battery of an electric vehicle. Opila et al. [10] introduce virtual oscillator control of voltage-sourced and current-controlled power converters. The paper is highly theoretical and lacks a direct practical connection to the real world. Anuradha et al. [11] introduce the design and analysis of a non-isolated three-port single ended primary inductance converter (SEPIC) for renewable energy source applications, where the input section of the converter is used as a modular section for interfacing different renewable energy sources. The problem in the paper is that the PV interfacing is not considered correctly, which is still quite a common issue in renewable energy interfacing studies. Park et al. [12] introduce the methods to control the speed of a turbine generator, where the energy of the system is extracted from different heat sources. The control algorithm indirectly estimates the required speed of the generator. The rest of the converter system is similar to the full-power converter systems used in wind power interfacing. Yan et al. [13] study the inertia and damping characteristics of a doubly-fed induction generator (DFIC) during a grid fault. The paper proposes methods to control the frequency in such a manner that the system stability is improved. Suntio [14] provides small-signal models for a peak current mode-controlled boost converter, which operates in discontinuous operation mode with all the power stage parasitic elements included. It is shown that the modeling technique developed in the early 2000s yields accurate models for the boost converter as well when the load resistor effect is removed. Yang et al. [15] study the oscillation phenomenon observed to take place between the parallel-connected grid-tied inverters in weak grid conditions. The damping method is based on adding two virtual impedances in series and in parallel with the original output impedance of the inverter. The practical experiments show that the proposed technique works. Xu et al. [16] introduce methods to provide grid-supporting functions in photovoltaic systems by utilizing battery energy storage to create a virtual synchronous generator. The power system is claimed to be able to operate without phase locked loop grid synchronizing. The concept is validated with simulations. Hu et al. [17] study the coordinated control of virtual synchronous generators. The developed strategy is validated by simulations. Liu et al. [18] study the ultra-short-term wind power prediction methods, which are based on multivariate phase–space reconstruction and linear regression. The developed method is shown to be more accurate than earlier developed methods. Li et al. [19] study the design of phase lock loop-based grid synchronizing aiming for fast transient behavior. The proposed concept is based on the application of adaptive notch filtering and moving average filtering as the inner loop of the phase locked loop. The experimental validation proves the improvement of the proposed technique. Salgado-Herrera et al. [20] study the total harmonic distortion (THD) in wind energy systems showing that the utilization of an active front-end converter to provide the DC-link voltage will reduce the overall THD. The concept is verified by simulation. Hu et al. [21] propose an improved droop control method based on the conventional droop control with a washout filter controller. The proposed method is validated by utilizing the hardware-in-the-loop (HIL) method. Merabet [22] studies the application of adaptive sliding mode speed control of a wind energy generator. The proposed technique is validated experimentally by utilizing a small-scale prototype system. Miceli et al. [23] study harmonic mitigation by means of computational methods in a single-phase five-level cascaded H-bridge multilevel inverter. The developed method is experimentally validated with a small-scale prototype. Tran et al. [24] study the control design of a grid-connected inverter under distorted grid conditions based on the linear-quadratic regulator technique. The proposed control technique is based on the internal model control principle. The experimental validation shows that the proposed technique works well. Li et al. [25] study the effect of adaptive resonant controllers on the stability of the grid-connected inverters under weak grid conditions. The validation of the studies is performed experimentally. The paper provides useful tips for implementing adaptive resonant controllers to avoid problems. Yan et al. [26] study the control methods of grid-connected inverters to make them mimic the characteristics of a synchronous generator. The proposed techniques are validated by simulations, which do not necessarily convince the readers. Yan et al. [27] study the adaptive maximum power point tracking-based control to create the properties of a synchronous generator. The reader may have problems understanding the proposed techniques because the authors have not explicitly specified in which operation mode the system is working. Dalala et al. [28] propose an algorithm for thermoelectric generators to track the maximum power point (MPP). The method is based on indirectly detecting the open-circuit voltage and estimating short circuit current, which are then used for tracking the MPP. The experimental waveforms show that the proposed technique tracks the MPP very quickly. Wang et al. [29] study the energy management in a micro-grid based on demand response. An optimization strategy is developed for minimizing the operating costs. The strategy is tested on a real case study. Liang et al. [30] study the balancing of the charges of embedded storage batteries in series-connected switching modules. The proposed control strategy is experimentally tested and shown to work well.

2.4. Discussions

The published papers represent the current main topics related to renewable energy. The lack of full understanding of the dynamics of the converters, which are applied in a renewable energy system, still dominates the discussions in this field even if hundreds of papers have already been published where the true nature has been explicitly presented. The lack of experimental validation will also usually reduce the acceptance of the information.

Conflicts of Interest: The authors declare no conflict of interest.

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