



Editorial

Methods and Concepts for Designing and Validating Smart Grid Systems

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Abstract: This Editorial provides an introduction to the Special Issue “Methods and Concepts for Designing and Validating Smart Grid Systems”. Furthermore, it also provides an overview of the corresponding papers that were recently published in MDPI’s *Energies* journal. The Special Issue took place in 2018 and accepted a total of 19 papers from 19 different countries.

Keywords: design, development and implementation methods for smart grid technologies; modelling and simulation of smart grid systems; co-simulation-based assessment methods; validation techniques for innovative smart grid solutions; real-time simulation and hardware-in-the-loop experiments

1. Introduction

Energy efficiency and low-carbon technologies are key contributors to curtailing the emission of green-house gases that continue to cause global warming. The efforts to reduce green-house gas emissions also strongly affect electrical power systems. Renewable sources, energy storage systems and flexible loads provide new system controls, but power system operators and utilities have to deal with their fluctuating nature, limited storage capabilities and typically higher infrastructure complexity with a growing number of heterogeneous components. In addition to the technological change of new components, the liberalisation of energy markets and new regulatory rules bring contextual change that necessitates the restructuring of the design and operation of future energy systems. Sophisticated component design methods, intelligent information and communication architectures, automation and control concepts, new and advanced markets, as well as proper standards are necessary in order to manage the higher complexity of such intelligent power systems that form the smart grid.

Due to the considerably higher complexity of such cyber-physical energy systems (CPES), constituting power system, automation, protection, information and communication technology (ICT), as well as system services, it is expected that the design and validation of smart grid configurations will play a major role in future technology and system developments. However, an integrated approach for the design and evaluation of smart grid configurations incorporating these diverse constituent parts remains evasive. Validation approaches available today focus mainly on component-oriented methods. In order to guarantee a sustainable, affordable and secure supply of electricity through the transition to a future smart grid with considerably higher complexity and innovation, new design, validation and testing methods appropriate for CPES is required. Papers that present results related to the design and validation of smart grid systems have been targeted by this Special Issue.

2. Content of the Special Issue

The accepted and published papers address a wide range of challenging and interesting methods and concepts in the domain of designing and validating smart grid systems, which can be mainly grouped into six clusters related to the following:

- (1) System design methods;
- (2) Simulation concepts;
- (3) Co-simulation approaches;
- (4) Hardware-in-the-loop (HIL) experiments;
- (5) Laboratory tests; and
- (6) Optimisation techniques.

Table 1 provides a brief overview of the assignment of the papers to the aforementioned clusters.

Table 1. Topics and included papers of the Special Issue.

Topic	References
System design methods	[1–3]
Simulation concepts	[4–7]
Co-simulation approaches	[8,9]
Hardware-in-the-Loop experiments	[10–14]
Laboratory tests	[15,16]
Optimisation techniques	[17–19]

2.1. System Design Methods

Often, the development of new approaches and methods begins with the design of the target system. This forms the basis for the implementation, which in turn can be evaluated in various ways.

For example, in [1], a market design was developed that addresses system balancing products within a web-of-cells (WoC) architecture. The focus is on a solution that is as economically efficient as possible. Based on a literature search, as well as analysis methods, different possibilities were compared. In contrast, the authors in [2] explored ways to transfer approaches from other domains, such as healthcare, to the domain of smart grids. In particular, within the framework of the project “Integration of the Energy System” (IES), Austria, interoperable communication will be the focus of attention. An essential element of this is a standard from the International Electrotechnical Commission (IEC), namely IEC 61850. A third approach to architectural modelling is the smart grid architecture model (SGAM) [3]. The SGAM, which provides a structured basis for the design, development and validation of new solutions and technologies, will be analysed in terms of its past use in Europe and its adaptations to other domains.

2.2. Simulation Concepts

A first and early approach to evaluate new concepts is simulation. With simple models, quick first insights can be gained, which can lead to the successive improvement of the solution. Simulations can be used in many different ways.

In [4], simulation was used to analyse a four-cell reference power system to evaluate a new controller. This controller follows a new strategy for dynamically adjusting the power frequency characteristic based on the imbalance state. The authors in [5] were able to demonstrate through simulations that their proposed effective filtering approach (EFA), to improve network traffic performance for the high-availability seamless redundancy (HSR) protocol, reduces network unicast traffic by up to 80%. Simulation of an unbalanced 12.47-kV feeder with 12,780 households and 1000 electric vehicles (EV) under peak and auxiliary load conditions was conducted in [6] to analyse a

three-phase loss allocation procedure for distribution networks. The authors in [7] in turn simulated a well-known IEEE 14 bus test system for analysing a developed data mining algorithm. The data came from phasor measurement units (PMU), and the algorithm pursued the goal of better integration of wind turbines.

2.3. Co-Simulation Approaches

In some cases, it is not possible to determine in advance how the environment will look for a new solution. This also implies that it is not clear which factors influence a new solution. This is where the co-simulation approach has become established. Different simulation environments and models are coupled in order to map complex overall system scenarios.

Since the term co-simulation can be a broad field that takes very different depths of detail into account, the authors in [8] devoted themselves to a systematic structuring of different approaches. The authors in [9] used a specific co-simulation platform to demonstrate that the public mobile telecommunication system 4G long-term evolution (LTE) is applicable for fault location, isolation and system restoration (FLISR) applications in radially- and weakly-meshed medium voltage distribution networks.

2.4. Hardware-in-the-Loop Experiments

However, in comparison to co-simulation, if the deployment environment of a new solution, such as that of a controller, can be clearly defined, HIL-based tests are an obvious choice. Here, the real environment of the controller is simulated, and its behaviour is evaluated.

In the field of energy supply, a specific form of HIL, power hardware-in-the-loop (PHIL), has become established. Since the interface between the virtual part (simulated environment) and the real part (for example, the controller) is of the highest importance here, so far, many interface algorithms (IA) have been developed. The authors in [10] examined which IA were suitable for which PHIL experiments. In [14], two concrete approaches—a conventional PHIL design and a simplified structure based on a quasi-dynamic PHIL approach—were compared. Another important aspect of PHIL experiments is that the simulated system or its behaviour may be heavily dependent on whether the hardware being tested is connected. In particular, the initialisation of a real-time simulator (RTS) can lead to problems here. This problem was addressed by the authors in [12] by introducing a procedure for initialising PHIL simulations for synchronous power systems. Another field of application for PHIL is microgrids or their control; in particular, distributed concepts, e.g., through the implementation of multi-agent systems, and experiments are offered for PHIL in [13]. The simulation of PMU has already been mentioned, and distribution phasor measurement units (D-PMU) and micro-synchrophasors (micro-PMUs) are also addressed in [11]. Specifically, the authors presented a vendor-agnostic PMU real-time simulation and HIL (PMU-RTS-HIL) approach.

2.5. Laboratory Tests

The methods described so far for the validation of new approaches are characterised by a predominant use of software. Solutions that have a higher degree of maturity are then validated in lab-based tests before being field-integrated into real systems.

The authors in [15] dealt again with microgrids. They investigated whether distributed voltage control systems can be a serious alternative to centralised approaches. For this purpose, the development, the structure and the operation of a corresponding hardware-based lab test stand was described. In a further laboratory setup, the behaviour of active distribution networks was analysed, which were strongly penetrated by renewable energies [16]. This was examined by means of various parameters (tap changers of the transformers in the primary substation, reactive power injections of the renewable energy sources and active and reactive power exchanged between adjacent feeders being interconnected through a direct current link), to show what an optimal control can look like.

2.6. Optimisation Techniques

In addition to the development of new solutions, a significant part of research and development in smart grid systems is also concerned with the optimisation of existing approaches and methods. However, these optimisations can only be performed if the system was fully understood in advance. This in turn implies extensive prior validations.

The authors in [17] dealt with an optimisation of the coordination of reserve allocations in multiple-cell-based power systems. The starting point was the implementation of linear decision rule (LDR)-based guidelines. An energy market-based optimisation was pursued by the authors in [18]. The intended goal was to offer flexibility bids for a real-time balancing market. Finally, in [19], the concept of microgrids was focused on again. The authors investigated how microgrids prevent weather-related network outages by creating more robust structures. The result was an optimised power supply.

3. Conclusions and Outlook

All 19 papers (17 articles and two reviews) described exciting new design, validation and testing methods for CPES. Several of them were done in the context of funded research and development projects, especially with support from the European Union framework programmes. They covered approaches from system design to (co-)simulation and HIL, to laboratory tests and optimisation. With those methods in hand, the validation on system level becomes possible. However, future research and technology development are still necessary in order to further develop those approaches, to harmonise them and to provide corresponding frameworks and tools.

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Abbreviations

CPES	Cyber-physical energy system
D-PMU	Distribution phasor measurement unit
EFA	Effective filtering approach
EV	Electric vehicle
FLISR	Fault location, isolation and system restoration
HIL	Hardware-in-the-loop
HSR	High-availability seamless redundancy
IA	Interface algorithms
ICT	Information and communication technology
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IES	Integrating the energy system
LDR	Linear decision rules
LTE	Long-term evolution
Micro-PMU	Micro-synchrophasor
PHIL	Power hardware-in-the-loop
PMU	Phasor measurement unit
RTS	Real-time simulator
SGAM	Smart grid architecture model
WoC	Web-of-cells

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