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Editorial

Nonlinear Technologies in Advanced Power Systems: Analysis and Control

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This century has been considered the age of *Complexity*, and therefore that of nonlinear circuits and systems. Complexity includes nonlinear dynamical systems and their interconnections. In parallel to this multidisciplinary research, nonlinear technology in various fields has been strongly developed.

The term nonlinear technology includes both nonlinear devices, and methods and numerical strategies. All these items are considered to design new devices and equipment that can achieve added values with respect to those designed following linear strategies. In spite of this appealing adventure, researchers must face new problems and adopt design techniques avoiding and limiting the classic drawbacks of the nonlinearity.

In this context, both the themes of complexity and that of the nonlinearity find an extremely timely field in the context of modern power systems and are considered as interconnected networks of quite different, mainly nonlinear, components with complex dynamics and distributed in the space even connected by large scale networks. It has always been said that power systems are the most complex plant that an engineer could handle and control. Moreover, the integration of small green grids with classic energy buses involves further strategies to guarantee the correct behavior of the global plant. Of course, joining advanced power electronic modules and DC/DC or DC/AC converters with digital control systems is of particular interest for the future investigations on power systems in the age of ecological and digital transition, items that make the future studies on power plants a fascinating and useful research area. Therefore, from a research point of view, it represents one of the more multidisciplinary areas in engineering.

In this editorial, an essential scenario of several aspects regarding the nonlinear technologies will be reported with reference to selected papers published in the journal *Energies* during the last two years, thus providing an updated vision of what is being currently studied in the field.

Various items are investigated, and even if the papers include innovative outstanding elements in the area of nonlinear technology, the contributions do not only follow the traditional general guidelines in studying power plants. The selected papers are strongly interrelated among each other in several points, as quite different problems converge in the area of advanced power plant problems. Therefore, selecting the proper keywords that, in our opinion, characterize the research, allows us to build the correlation matrix reported in Table 1, which guides the reader towards a global view of the contents of the considered advanced research papers.

Moreover, a short summary of each selected paper is reported in the following part of this editorial. The order of the discussed papers has been chosen to focalize the attention of the reader on the various subjects, avoiding group papers on the basis of common peculiarities.

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Table 1. Correlation matrix of the selected keywords.

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]
Power systems networks	X	X		X	X	X		X			
Micro power grids	X			X			X	X			X
Harmonic analysis		X								X	
Observability				X							
Frequency domain analysis		X	X		X					X	
Large-scale systems analysis						X		X			X
Nonlinear control techniques	X						X	X			X
Nonlinear characterization of components		X	X		X		X	X		X	
DC/DC converters	X		X		X		X		X		X
Optimization	X			X							X
Performance analysis		X		X					X	X	
Artificial nonlinear neural networks									X		

In [1] Armghan et al.'s study, the dynamical behavior of a microgrid is investigated. Moreover, the mathematical model is introduced by taking into account the energy storage elements, such as batteries and ultracapacitors. The DC/DC converting system is clearly shown and the systematic scheme of the integration of the presented microgrid with a DC bus is discussed, remarking the aspects of the time-varying load profile and that of the alternative power sources. The fundamental aspect is the introduction of a nonlinear control scheme, where a double integration nonlinear sliding mode controller is presented and accurately discussed with the mathematical model details. The DC/DC converter is carefully shown and an optimization procedure based on the genetic algorithm is proposed for tuning the controller parameters. The Lyapunov theory, in order to guarantee the robust stability of the system, is presented.

The contribution presented in the paper [2] by Michalec and coauthors regards an interesting experimental analysis of harmonic distortion in low power networks considering more common nonlinear components. The topic is of significant importance due to the fact that the authors discuss daily nonlinear loads, such as that of the power supply in a smartphone or in a computer, including also more power consumption loads, such as coffee machines; it is shown that more frequency components are injected in the network and not only the third order but also the fifth order are dominant in the signals. The nonlinearities decrease the quality of the network power, even if the load components are considered negligible.

Tousi and Ghassemi presented in their contribution [3] nonlinear technology aspects regarding the dielectrics in bandgap power modules, where high-voltage signals must be handled in order to reduce the size of the active components made in SiC or GaN technologies. The characterization of polymer dielectrics in terms of nonlinear behavior with respect to frequency and temperature has been proposed. Through coupling a smart design approach from geometrical consideration, an improvement in small size devices is shown.

Theodorakatos and his coauthors in [4] present an optimization algorithm in order to locate the so-called phase measurement unit (PMU) in a power network. The problem is of wide general interest and in fact, PMU allows for the observability of the network. Ideally, a large number of these equipment will give an optimal information measurement set, but practically, a limited number of PMUs must be located. The authors present an innovative optimization strategy in order to select a reduced number of PMU units. The optimization algorithm is tested on an IEEE standard bus; moreover, its peculiarities allow it to be used in other networks and also to be reconfigured for locating other equipment in an optimal way.

In [5], Faifer and coauthors present new technical and analytical details, allowing the characterization of mathematical models that evaluate the impact of nonlinear loads in power networks. The results are also used to evaluate the harmonic components. The approach is based on a strategy that allows one to couple the transfer function methods with the Volterra series approach. Suitable results are shown considering a diode bridge electronic circuit.

The contribution of Ugwuanyi and others is reported in [6], where a very interesting approach in the modal analysis of large-scale power systems is presented. Modal analysis has been a widely discussed theme in the study of the dynamical behavior of the power plant. In fact, the eigenvalues map gives complete information about the dynamical state of the network. The authors present a method that improve some existing strategies, where not only the linear part of the plant model is considered. The technique generally leads to high efforts of computation; moreover, in the paper, the authors present a strategy that improves the computational cost by reducing the number of parameters taken into account in the nonlinear part. The results are quite interesting. The authors report in detail the power plant model and it is clear that this theory could be also applied to hybrid power plants.

The very important contribution [7] proposed by Wang and various coauthors is addressed to the area of DC/DC converters regarding their robust control. In fact, the authors propose a passification strategy in order to guarantee the strong stability of the converter. The study is supported by an accurate analytical analysis made using the Lyapunov approach. Moreover, numerical results in phase portrait representation are included. The experimental results prove the suitability of the approach. The paper includes several items of nonlinear technology, such as the nonlinear strategy, the electronic nonlinear components and the possible integration of a strongly robust controller in a complex network.

Papageorgiou and other authors in [8] remark the complexity of a power plant system. The distributed generation problem makes the global control strategy a key-point of the correct behavior of the systems. The authors remark the various components inside the complexity of the plant, electromechanical components, electronic devices, and several pieces of equipment that form the elements of the global system. The authors approach the problem of a global model including all the components and propose in the case of modelling the core of the systems, the controlled impedance admittance torque (CIAT) system. The strategy allows one to formulate a detailed model that is suitable to be handled for the global stability of the system.

Jumilla-Corral and his coauthors propose in the contribution [9] a neural network approach for harmonic prediction and modelling in grids with photovoltaic sources. The system is nonlinear and the artificial neural networks with a NARMAX intrinsic model are nonlinear. The authors show that an artificial nonlinear network can help to predict the behavior of a nonlinear plant. This is another real application of nonlinear technologies.

Rozegnał et al. present an interesting contribution [10], where cable line losses are studied. Indeed, in order to distribute energy, cables are needed. The nonlinearity of the load leads to dissipation in the cables. The losses are evaluated, and interesting results are reported in tables and graphs. The study is performed with particular attention to the skin effects and to the role that harmonics play in this context.

Predictive control is one the more interesting strategies used in automatic control application today and Trigkas and his coauthors in the paper [11] present an original contribution where nonlinear predictive control strategies are introduced for storage energy management in interconnected microgrid networks. The mathematical model of the management system is presented and the platform including the SCADA system is proposed for real-time applications. The paper summarizes the key-points of advanced control, the integration in microgrids of DC/DC converters and the optimization of the global system.

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