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Experimental Identification of Uncertainties in Dynamics of PWM Buck Converter

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Abstract: The paper is dedicated to the development of experimental bifurcation analysis and is focused on the research of uncertainties in dynamics of an operating process in application to PWM buck converters. The experimental bifurcation analysis follows the approach which allows to identify some qualitative thresholds through the successive evolution of the system behaviour caused by the complex interplay between bifurcation and noise components. In according to the approach the 2D-operating process domain is built and is divided onto three kinds of the uncertainty zones. The computational and experimental results are discussed from the practical experience concerning the ways to prevent the abnormal processes in dynamics of PWM buck converters.

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Keywords: PWM buck converter; experimental bifurcation analysis; experimental parametrical diagram; instrumental time series; uncertainty zone; real-time identification; stability margin.

1. INTRODUCTION

PWM converters represent switching systems in dynamics of which different bifurcation phenomena are known, and the researches in this field continue from the second part of the XX century till the present. The majority of publications are devoted to computer simulations based on mathematical models. The incontestable advantage of the mathematical modeling is connected with possibility to study both variety and regularities of nonlinear dynamics without restrictions on the dimensionality, ranges, initial conditions, and so on. In particular, the variety of different kinds of sub-harmonic, quasi-periodic and chaotic processes is revealed by the computer simulations and is confirmed by the experimental way, for example, Maity et al. (2005), Kocewiak et al. (2007), Kolokolov and Monovskaya (2007, 2009a), Kavitha and Uma (2008), Chen et al. (2008). Nevertheless, the number of publications devoted to the experimental researches of PWM converter nonlinear dynamics remains moderate, and such publications are aimed mainly at the qualitative verification of computer simulated results. In other words, the presence of certain nonlinear phenomena is confirmed, but a good quantitative correspondence between computational and experimental results is achieved only with the quite narrow range of parametrical variation.

At the same time, it is observed the tendency to be more active the interest in subtle and intricate nonlinear phenomena which are caused by uncertainties of different nature, for example, Basak and Parui (2010), Monti and Poinci (2010), Yu et al. (2012), Kolokolov and Monovskaya (2013a), Zhou et al. (2013). Concerning this state of affairs it is necessary to notice several important peculiarities of PWM converter dynamics. First, the scenario of dynamics evolution through 1-2-4-… period doubling is the baseline one, where the 1-process dominates, but multiple attractors exist within the operating process domain, for example, Kolokolov and Monovskaya (2007, 2013b). So, there are potential possibilities to loss the operating process stability before the bifurcation boundary of the period doubling. Second, the process of energy conversion occurs with high frequency of the power part structural changes (tens and hundreds kHz). Any switch of power key can lead to a splash of variables at the commutation moment, and the magnitude of the splash can substantially exceed the background level of an acting noise. The corresponding deviation of a phase point from the limit cycle of the operating process can lead to undesirable distortions of the energy conversion process within the baseline scenario. Third, development of energy conversion systems are connected with the both increase in PWM frequency and widening of the ranges of working parameters. So, it seems to be prospective that the complex interplay between bifurcation and noise components of the dynamics can influence on the quality of pulse energy conversion processes to some greater extent.

Computational and experimental researches of such nonlinear phenomena exhibit the necessity to pay more attention to the experimental constituent since the observable interplay can be identified only as extremely rare, capricious and irregular phenomena, for example, Kolokolov and Monovskaya (2013a, b). Intermittency phenomenon is one of the most obvious examples which are excited by such interplay. The intermittency is realized within a multiple attractor, and it means that a phase point attracts alternately towards one or another attractor. Taking into account the abovementioned reasons the information growth by use of more intelligent procedures of experimental researches seems to be one of the promising directions to develop the experimental bifurcation analysis. It allows to increase essentially the number of iterations to build bifurcation diagrams, to widen the dimensionality of the controlled variable parameters, to use

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more combinations of initial conditions, step and direction, and, finally, to get possibility to compile more instrumental data to reveal and analyse the subtle nonlinear effects caused by the complex interplay between bifurcation and noise components. The paper is dedicated to the development of experimental bifurcation analysis and is focused on the research of uncertainties in dynamics of an operating process in application to PWM buck converters. The operating dynamics is considered in 2D parametrical space under the wide-range variation of both the load in a power part and the proportional stage gain in a control part. The obtained experimental results were made on the setup of a PWM buck converter.

The main idea consists in the following. A bifurcation boundary can be used in algorithms of dynamics identification and forecasting as one of the main references, for example, Kolokolov and Monovskaya (2007, 2009a, b). But for systems with a variable structure, there are several qualitative thresholds, through which the successive evolution of the system behavior occurs within the operating process domain, Kolokolov and Monovskaya (2013a). So, the researches follow the approach to the formalized experimental bifurcation analysis presented in Kolokolov and Monovskaya (2013b) to identify such thresholds. And we try to reveal which of the thresholds corresponds in the best way to the reference boundary used in the algorithms. It allows to simplify the preliminary tuning of the algorithms to prevent the loss of the operating process stability.

2. BIFURCATION BOUNDARY OF OPERATING PROCESS

Our researches are focused on the dynamics of the synchronous buck converter with PWM control and the proportional regularity law. The equivalent circuit of the converter is presented in fig.1a. The corresponding mathematical model to remain the physical essence of PWM represents the system of differential equations with a variable structure:

$$\frac{dX}{dt} = AX + B(K_F(\xi)),$$

where A is a matrix of invariable coefficients; B is a matrix of the variable coefficients to describe two constant structures; X is a phase vector, including the inductance current *(i)* and condenser voltage *(u)*; K_F is a pulse function to change the structures in accordance with PWM control. Such model causes the "piecewise" dynamics, for example, Leonov (1959), Feigin (1970). A periodic process is described by the ratio (m) of its periodicity in relation to the unit periodicity (PWM-periodicity) and is noted as an "m-process". The ratio m is determined on the basis of Poincaré's periodicity condition. The scenario of 1-2-4-.. period doubling is the baseline scenarios of dynamics evolution, for example, Maity et al. (2005), Kocewiak et al. (2007), Kolokolov and Koschinskii (2000), Kavitha and Uma (2008), Chen et al. (2008), and 1-process of this scenario represents the operating process of PWM energy conversion. The considered hereafter 2D-parametrical space consists of a leading bifurcation parameter from the control part (the proportional stage gain, α) and a leading working parameter from the power part (the load, R_3).

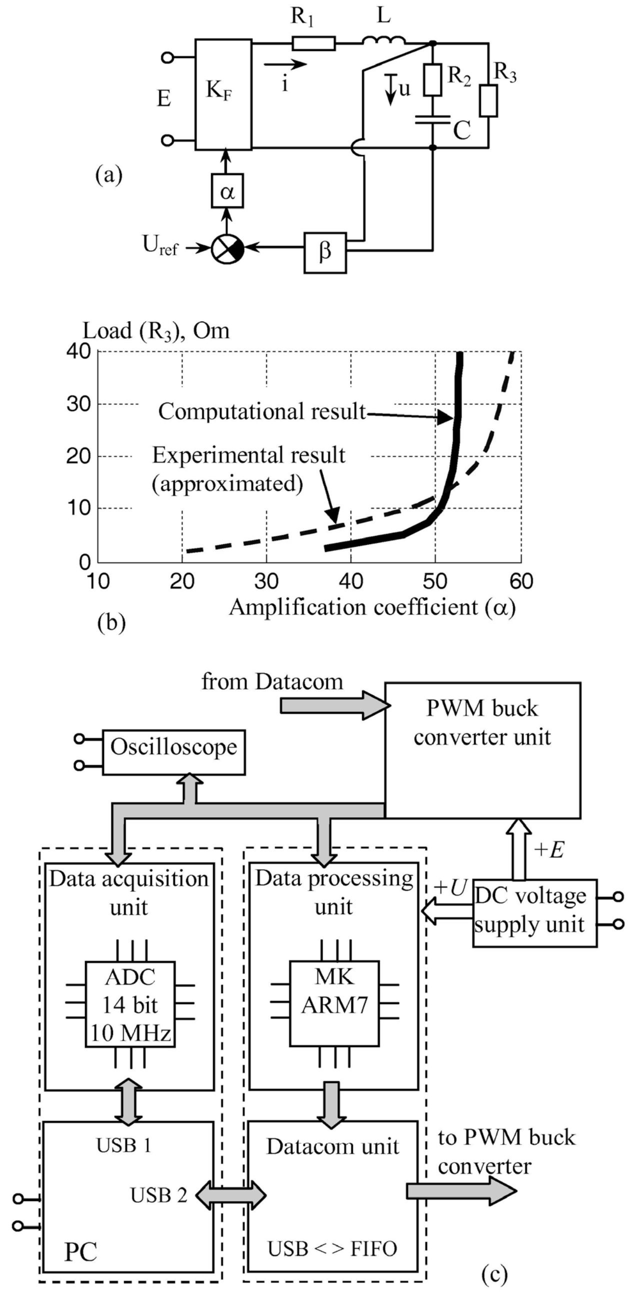

Fig. 1. The equivalent circuit of PWM buck converter (a); the bifurcation boundaries of the operating process domain built by computational (solid line) and experimental (dotted line) ways (b); the flow diagram of the experimental setup (c).

By the computational way a bifurcation point is calculated on the basis of the local stability condition in Lyapunov's terms, taking into account the specialized numerical method to sew the piecewise solutions, for example, Leine et al. (2000), Kuznetsov (2004), Giaouris et al. (2009). So, it is possible to accelerate the simulations of the bifurcation branches by the increase of the parametrical variation step between neighboring bifurcation points. By the experimental way for

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