Large-signal, Black-box Behavioral Modeling of Grid-supporting Power Converters in AC Microgrids

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ABSTRACT - Control of power converters in AC microgrids is well understood and established in the literature and in the industry, allowing the high penetration of distributed generation, electrical energy storage systems and controllable loads. These building blocks connected to the grid through power electronic converters open new opportunities to the expansion of microgrids in electrical power systems. A behavioral large-signal nonlinear polytopic model for grid-supporting converters operating as a current source is proposed in this paper. This model is able to represent the nonlinear behavior of the power converter and it is also very well suited for system-level modeling and simulation. The proposed modeling strategy can be easily extended to power converters in any other of the possible operating modes.

Keywords - Black-box; large-signal; microgrids; power converter modeling.

1. Introduction

A three-phase grid-supporting inverter connected to the AC grid and operating as a current source is represented in Fig. 1. In this operating mode, the main objective is not only to supply power to the existing loads, but also to contribute to the regulation of the frequency and voltage of the AC bus [1].

If we assume a grid with a dominant inductive behavior, the classical regulation curves of a droop controller are represented in Fig. 2:
At the same time, very often in microgrid design and implementation, COTS (Commercial Off-The-Shelf) power converters are selected and the manufacturers provide a limited amount of information about the converter performance and particularly about the converter dynamics. Generally, in order to simulate the system operation, black-box models of the power converters are required.

Figure 1. *Grid-supporting* converter as a current-source.

Figure 2. Frequency and Voltage classical regulation curves in a droop control.

In this paper, some of the above mentioned restrictions are overcome, proposing a **large-signal, black-box modeling strategy** for three-phase power inverters connected to an AC grid.

2. **Black-box modeling**

Black-box models are used when the information about the internal structure of the converter is not available. In such situation, it is necessary to identify the converter transfer functions through experimental tests applied to the actual power converters.
In the paper, in a first step, it is assumed the representation of the actual converter by its detailed switching model and the required experimental test for black-box modeling are applied to the detailed switching model instead of the actual converter. This procedure for model generation is named *Virtual Identification Technique*, based on the application of a set of step functions to the input variables of the power converter switching model, collecting the data obtained from simulations.

In the proposed procedure, firstly a small-signal G-parameter model [3] is developed and later a large-signal model is derived using a polytopic structure. Details about modeling strategy will be given in the final paper.

3. Small-signal G-parameter model

The small-signal model for a three-phase power inverter was proposed by Boroyevich *et al.* in [3]. In the model, assuming a three-phase balanced and not distorted grid, AC voltages and currents are represented as DC variables in the dq framework using Park’s transformation (Fig. 3).

![Figure 3. Small-signal G-parameter model.](image)

4. Large-signal polytopic model

Polytopic models have been already proposed for converters working in DC microgrids [4], [5] and also, to some extent for AC microgrids [6]. In short, the idea is to obtain a collection of small-signal models around different operating points and to integrate them in a nonlinear structure by means of suitable nonlinear weighting functions (Fig. 4).
5. Case study

The proposed large-signal black-box model has been applied to a three-phase power inverter operating as a current source in *grid-supporting* mode. This inverter (P_{nom}=15 kW) is connected to a balanced three-phase AC grid (230 V/380 V, 50 Hz) and the input DC voltage is equal to 400 V. The controller is similar to the one represented in Fig. 1, including a droop controller for power sharing.

![Figure 4. Polytopic model nonlinear structure](image)

![Figure 5. Active and reactive power injection vs. frequency. Comparison between switching model and polytopic model](image)

In order to check the described black-box behavioral model and assuming an ideal AC grid, a perturbation in the grid frequency as the one represented in the upper part of Fig. 5 is injected. Active and reactive power injected by both the black-box behavioral model
and the accurate switching model used as a reference are compared. Both models behave very similarly.

6. Conclusions

In this paper a non-linear black-box modeling strategy based on virtual identification procedures is described. The goal is to enable the study of dynamic interactions produced by the interconnection of commercial power converters. This behavioral model shows a good accuracy in comparison with the results obtained from the accurate converter switching model. Details about the model construction and the experimental results will be given in the final paper.

References


