Black-box Commissioning of Grid Converters

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***Abstract*—The increase of grid-connected converters has highlighted the problem of harmonic interaction between multiple converters and the grid. This phenomenon can bring to network instabilities. A valid approach in order to study the stability of the overall system is to characterize the converter with a small-signal equivalent admittance model and stability analysis through the General Nyquist Criterion (GNC). This work analyses two different black-box methods to experimentally characterize the converter equivalent admittance model. The first method performs a voltage injection on grid side and evaluates the amplitude and phase of the converter current response. The second method performs steps on the grid voltage and evaluates the equivalent admittance based on the shape of the current transient response.**

I. INTRODUCTION

Grid-connected converters have seen an increase over the past few years in response to a major penetration of renewable energy sources (RES) and charging stations for electric vehicles (EVs). This phenomenon has shown evidence of **harmonic interaction issues between multiple converters and the power grid, even though these were individually stable**. Such issues must be further investigated by developing accurate inverter models. A valid technique is the characterization of the converter through a small-signal admittance model, which can be easily combined with models of other converters connected to the same network and the grid equivalent model. The obtained an overall equivalent model, *e.g.* the one in Fig. 1, can be used to asses the stability of the network by means of the Generalized Nyquist Criterion (GNC).

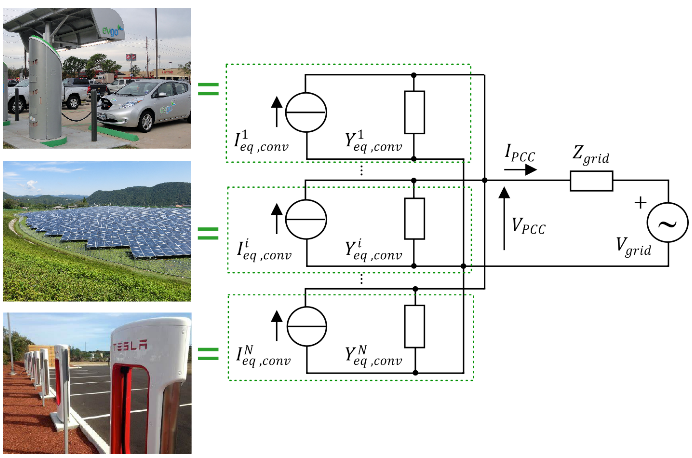

Figure 1: Overall equivalent model of grid and converters.

A theoretical derivation of the converter admittance model is possible but usually not feasible for commercial solutions, as manufacturers are concerned about the secrecy of their control algorithm and tuning procedures. Methodologies to experimentally obtain the equivalent admittance model with a black-box approach are thus becoming more and more appealing. **The goal of this thesis is to experimentally characterize grid-connected converters, comparing two different black-box approaches**. Results are then compared to the theoretical equivalent model. The considered converter structure is the one shown in Fig. 2.

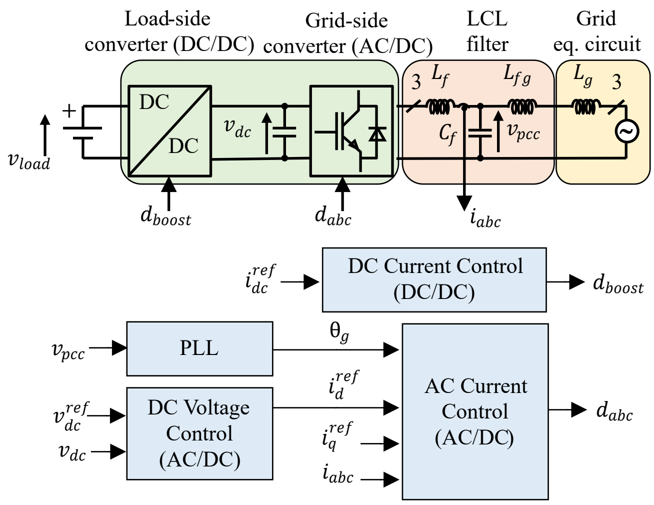

Figure 2: Converter structure on which the equivalent admittance is measured.

My **personal contributions** are:

- Analysis of technical literature on black-box methods for equivalent admittance measurement;
- Analysis of main System Identification methods;
- Sizing and experimental implementation of a discrete control on a grid-connected converter;
- Admittance measurement of a grid converter with the voltage injection method through simulation and experimental set-up;
- Admittance measurement of a grid converter with the transient analysis method through simulation;

II. VOLTAGE PERTURBATION METHOD

The voltage perturbation method consists in the calculation of the equivalent admittance point-by-point at every frequency of interest by performing multiple voltage perturbations on the PCC. For each point of the AC frequency sweep two tests are performed, with positive and negative sequence injected frequencies that are different in the three-phase reference frame but correspond to the same in the (d, q) frame. The measured voltage and current components at the frequency under test are then extracted through FFT. From these, the equivalent impedance is calculated as:

$$\mathbf{Z} = \mathbf{V} \cdot \mathbf{I}^{-1} \quad (1)$$

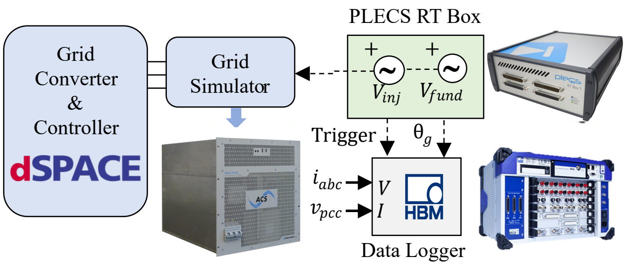

Figure 3: Block diagram of the experimental set-up for the admittance measurement through voltage injection method.

The experimental set-up that was considered is shown in Fig. 3. The converter and its control are structured as in Fig. 2. In order to produce the perturbation, a grid simulator was used. The perturbation amplitude was set at 0.1 p.u. with respect to the peak voltage, set at 120 Vrms, while the perturbation frequencies varied from 10 to 1000 Hz. The results are shown in Fig. 4.

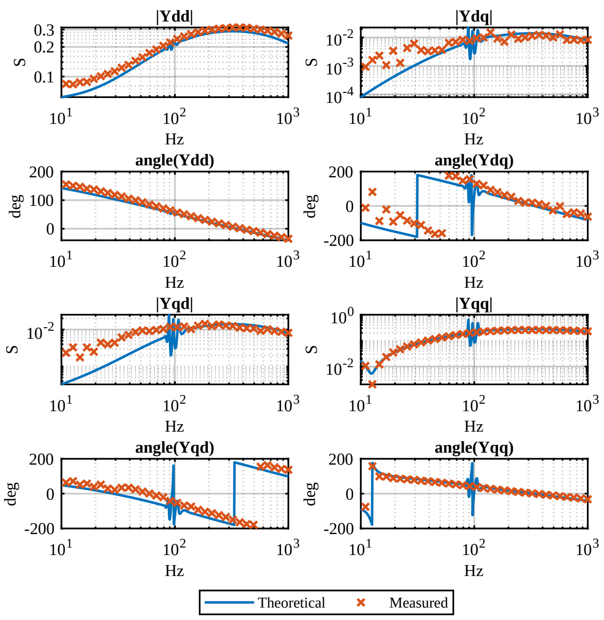

Figure 4: Comparison between theoretical and measured equivalent admittances of a converter working as a rectifier with $I_d = 10A$ and $I_q = 0A$.

III. Transient Analysis Method

The second approach characterizes the equivalent admittance by performing step perturbations on the grid voltage and evaluating the current transient response of the converter. The admittance transfer function can be estimated by using a System Identification method.

The tests were performed on the power electronics simulation platform *PLECS*. In order to measure all admittances, two steps must be performed. Fig 5 shows a diagram of the procedure.

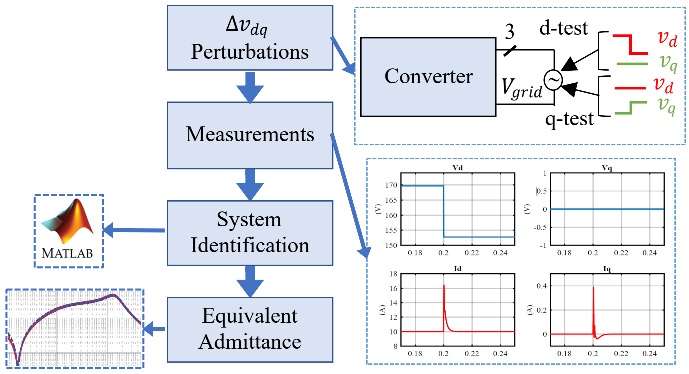

Figure 5: Test circuit for the transient analysis method.

The identification was done using the functions from the MATLAB System Identification Toolbox. The considered identification model was the *output error* model. The results are shown in Fig. 6.

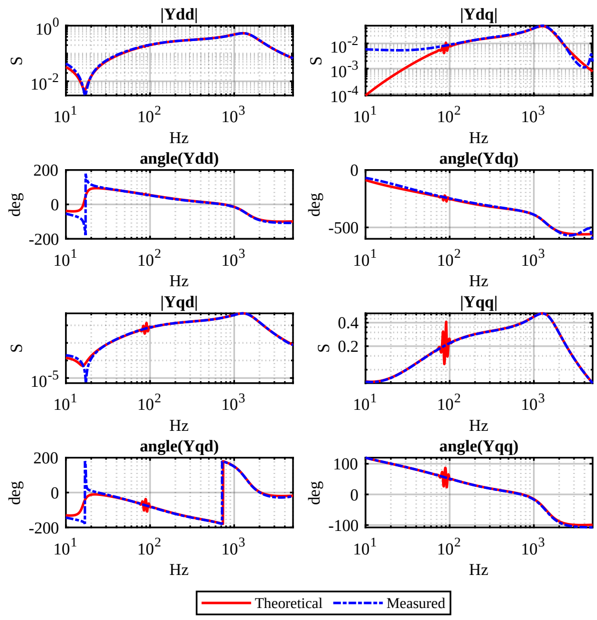

Figure 6: Comparison between theoretical and measured equivalent admittances with the transient analysis method with a converter working as a generator with $I_d = 10A$ and $I_q = 0A$.

IV. Conclusions

This work presented two methods for converter equivalent admittance estimation. Both methods were implemented on a simulation environment with good results, and the voltage injection method was tested on an experimental set-up as well. While valid on simulations, the experimental implementation of the transient analysis method still needs improvements. Future work will concentrate on this.