Experimental test bench for validating grid-forming strategies in V2G applications

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1. Introduction

The extended use of EV chargers to provide a bidirectional power flow between the battery and the grid is known as a V2G application. In V2G applications, EV chargers are able of both charging the battery and giving support to the grid. To interface the EV charger with the grid, the grid following (GFL) strategy is the most common approach. However, it has shown stability issues as power converter penetration increases. The grid forming (GFM) strategy, on the other hand, can contribute to the stability of the grid by behaving as a voltage source and mimicking synchronous generators.

This work will focus on the description of an experimental test bench developed to evaluate the performance of GFM strategies in V2G chargers.

2. Test bench description

The electrical scheme of the test bench is shown in Fig.1 and the corresponding setup is presented in Fig. 2. It is composed of a 96V bidirectional DC voltage source emulating the EV battery followed by a DC/DC converter and a DC/AC stage. A LCL filter after the DC/AC converter is needed to meet the power quality requirements of the grid. The LCL filter specifications are summarized in Table 1. A 200 Vrms three-phase grid is emulated by a Pacific Power 320AMX.

The control strategy of the power converters has been developed using a cRIO-9040, composed of a μC and a dedicated FPGA. Measurements are obtained from off-the-shelf sensors connected to the controller. For the management of the test bench, a Human Machine Interface (HMI) has been developed.

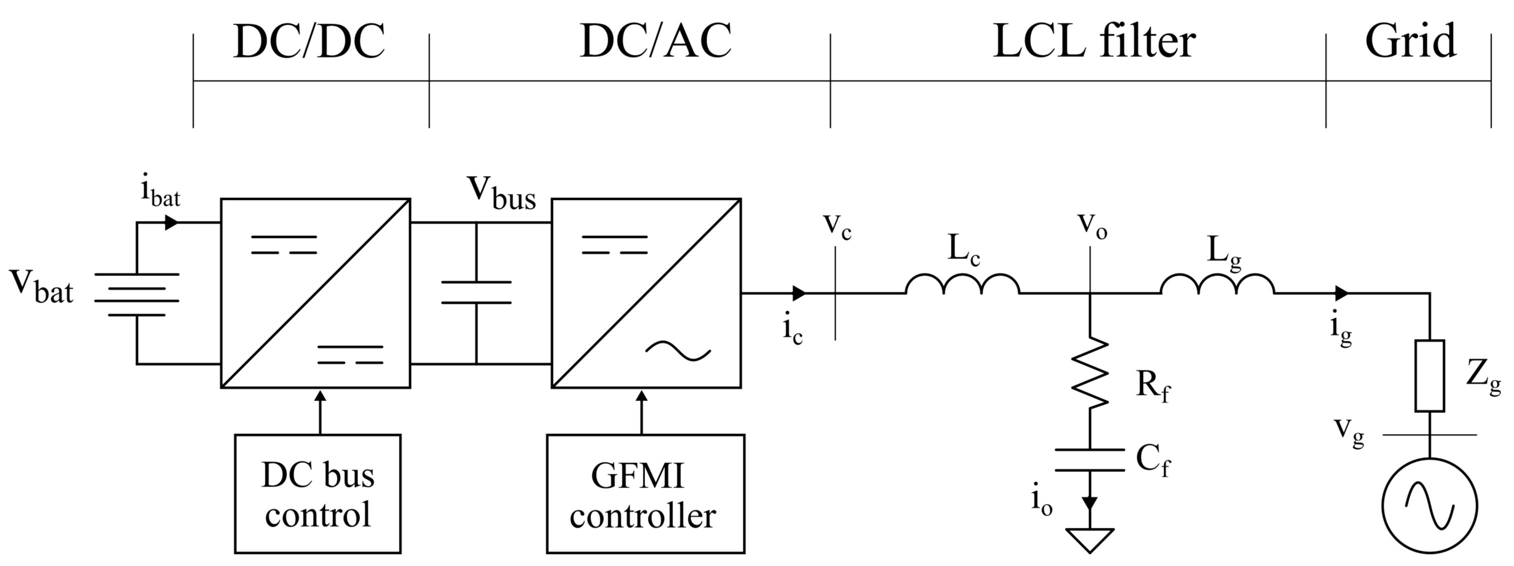

Fig. 1. Electrical scheme of the test bench.

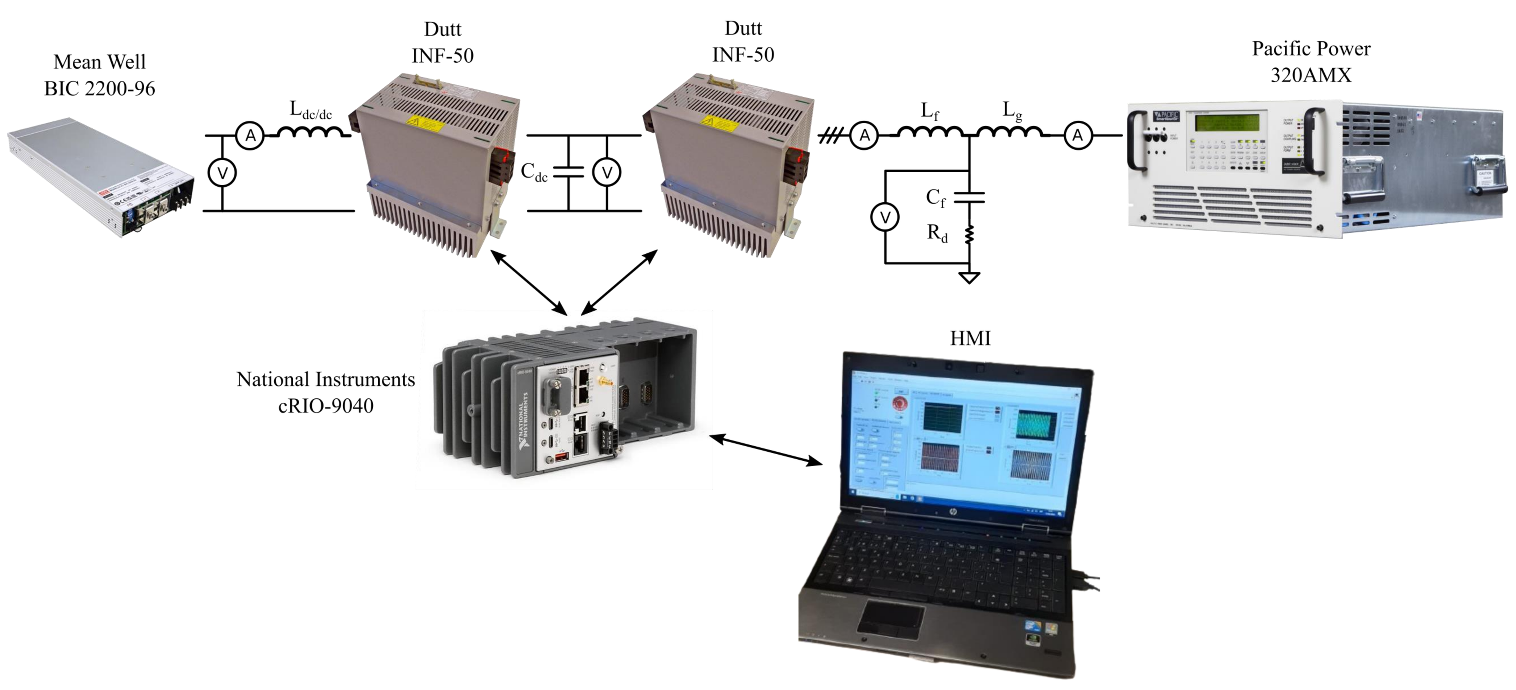

Fig. 2. Scheme of the test bench setup.

Parameter		Rated value
Current controller	k_p	0.49
	k_i	18.9
Virtual admittance	R_v	0.06 pu
	L_v	0.3 pu
PSL	H	4 s
	D_p	50 pu
RPC	τ_q	20 ms
	m_q	0.1 pu

Table 2. GFM controller parameters.

Parameter	Rated value
Base power (P_n)	625 W
Base line voltage (V_{gn})	200 Vrms
Base grid frequency (f_n)	50 Hz
Switching frequency (f_{sw})	10 kHz
DC bus voltage (V_{bus})	300 Vdc
Filter – Converter-side inductor (L_c)	0.05 pu (10 mH)
Filter – Capacitor (C_f)	0.05 pu (2.5 µF)
Filter – Grid-side inductor (L_g)	0.006 pu (1.2 mH)

Table 1. Rated values of the DC/AC stage.

3. GFMI controller

The GFM controller shown in Fig. 3 is divided in 4 parts:

1. **Power Synchronization Loop (PSL)**
   It is used to obtain the GFM angular frequency (ω_r) using active power balance. A Virtual Synchronous Generator (VSG) approach is used:
   $$\frac{d\omega_r}{dt} = \frac{1}{2H}\left(P^* - P + D_P(\omega_r^* - \omega_r)\right)$$
2. **Reactive Power Control (RPC)**
   It is employed to generate the GFM voltage reference (E) emulating the reactive power droop of SGs:
   $$E = v^* + m_q\left(Q^* - \frac{Q}{\tau_q s + 1}\right)$$
3. **Virtual Admittance**
   It emulates an impedance between the converter and the grid. It also removes the need of a voltage controller and ensures active and reactive power decoupling regardless of the grid impedance.
   $$E - v_{odq} = R_v i_{cdq}^* + \frac{L_v}{\omega_b}\cdot\frac{di_{cdq}^*}{dt} + j\omega_r L_v i_{cdq}^*$$
4. **Current Control**
   It is the inner control loop in charge of providing the converter dq output voltage reference (v_{cdq}^*). It is based on a PI controller with decoupling terms and capacitor voltage feedforward.
   $$v_{cdq}^* = \left(k_p + \frac{k_i}{s}\right)\cdot\left(i_{cdq}^* - i_{cdq}\right) + j\omega_r L_c i_{cdq} + v_{odq}$$

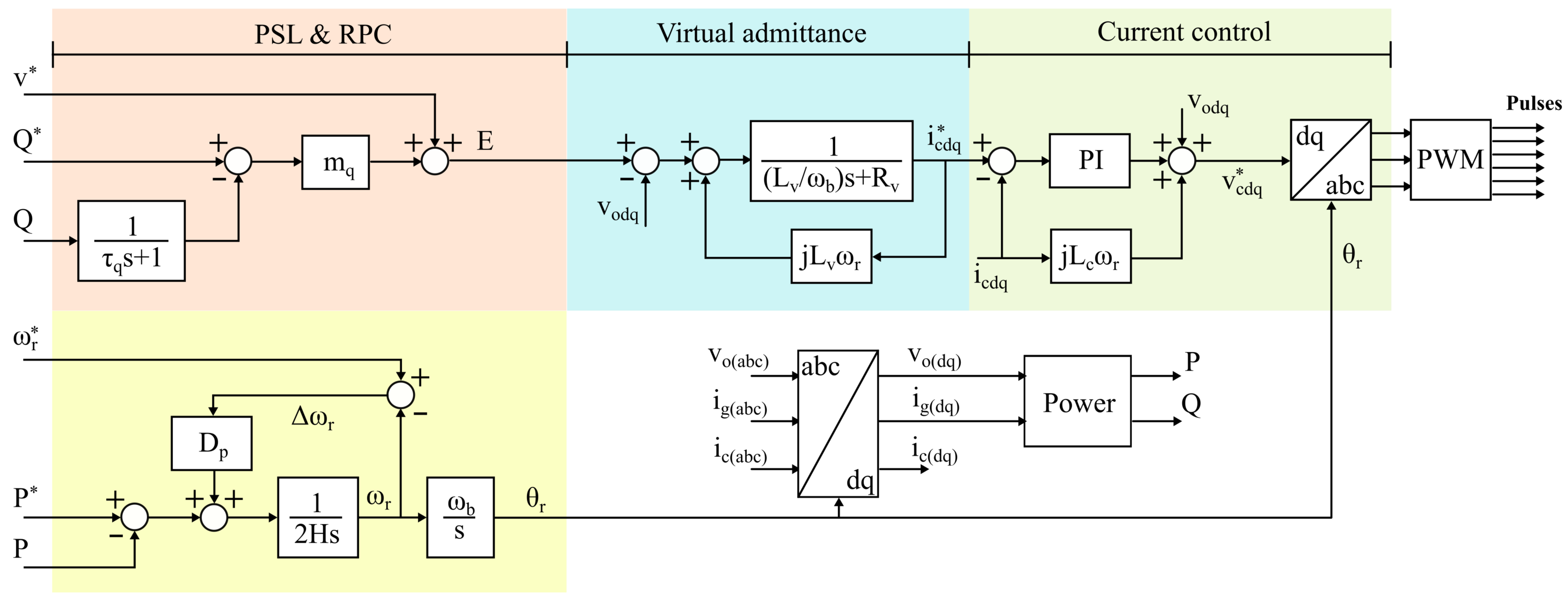

Fig. 3. Grid forming controller of the DC/AC stage of the V2G charger.

4. Validation results

The proposed test bench configuration has been validated under two possible real-world scenarios: 1) a modification of the charging power (active power reference) and 2) a grid frequency perturbation.. Both experimental V2G charger and simulation model (averaged) are compared.

- **Active power step setpoint**

Fig. 4 shows the response under a power step setpoint of 0.1 pu.. During the power transient, the internal frequency of the GFM inverter changes to modify the angle shift. After the transient, power setpoint is tracked without error. Reactive power is also affected, since active and reactive power decoupling is not perfect.

- **Grid frequency perturbation**

Fig. 5 shows the response under a perturbation. In this case, the grid frequency is increased by 0.002 pu. Inertia and primary frequency regulation services are provided by the V2G charger, as it can be appreciated in frequency and active power graphs. As stated before, reactive power is slightly disturbed due to decoupling issues. After the transient, the charger will support the grid injecting a constant active power.

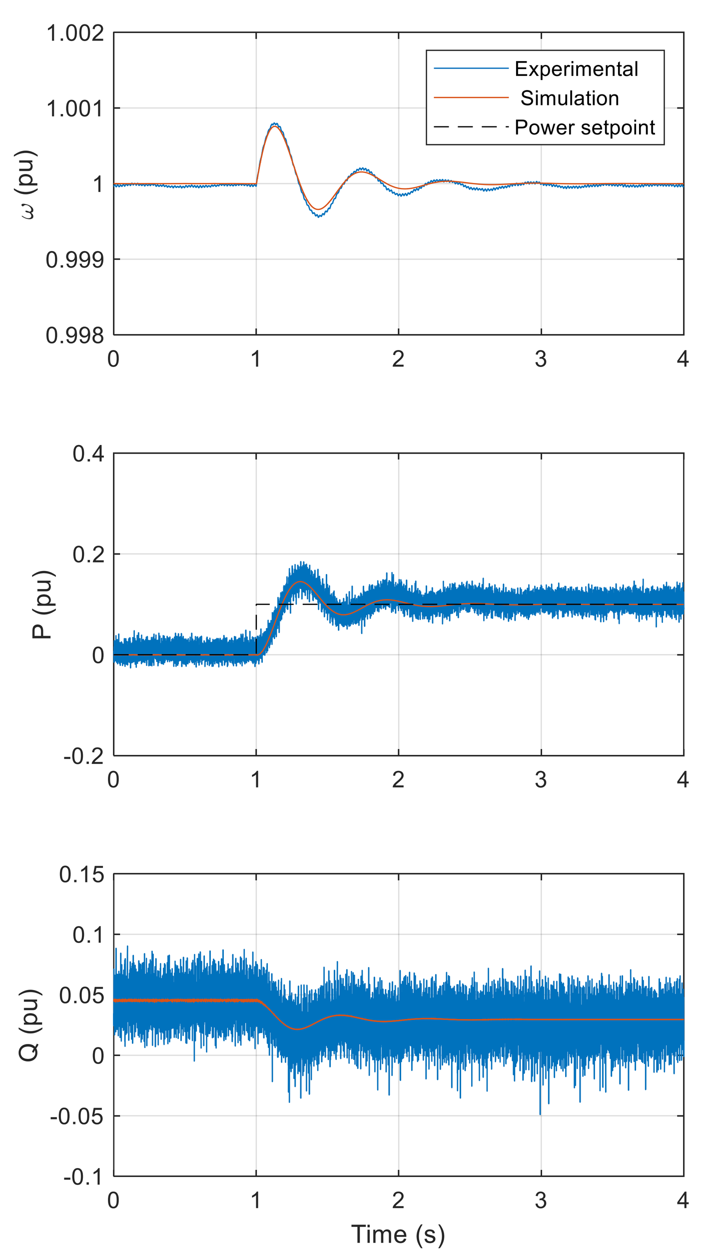

Fig. 4 Power step setpoint of 0.1 pu.

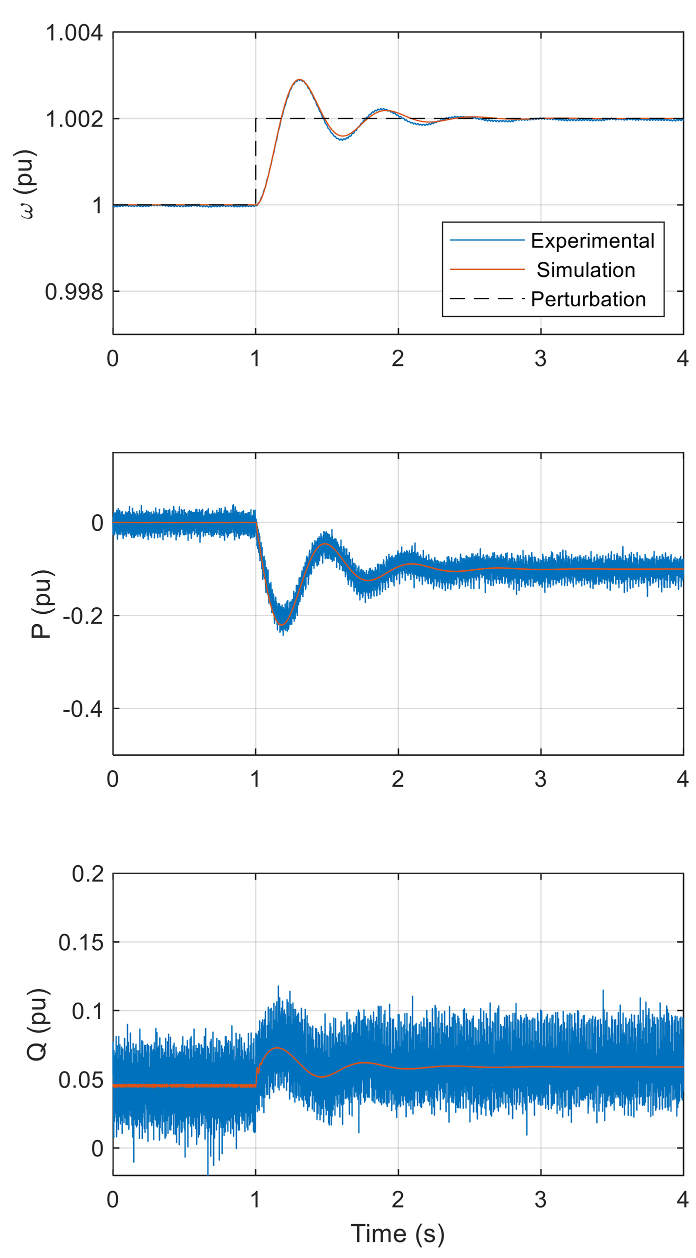

Fig. 5. Grid frequency disturbance of 0.002 pu.

5. Conclusions

- A test bench for developing GFM algorithms in V2G applications has been validated. The charger cannot only track the power references and charge the battery, but also provide inertia and primary regulation to the grid.
- The platform provides high versatility, serving as an experimental platform to evaluate the impact of different algorithms and parameter tuning in the performance of grid-connected V2G chargers.
- Real-time fast acquisition task of sensor and internal control signals will be crucial for research purposes.
- In future projects, the compatibility grid services and V2G chargers will also be evaluated in the proposed test bench.

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