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Robust Inner-Loop Control Design for a Single-Stage Single-Phase Onboard EV Charger with Uncertain Grid Impedance

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INTRODUCTION & AIM

The rapid growth of electric vehicles (EVs) has increased the demand for efficient and reliable onboard chargers. Single-stage single-phase AC/DC converters are widely used because of their simple structure and high efficiency. However, charger performance is strongly affected by grid impedance variations [1-2], which can reduce current regulation performance and system stability. Conventional controllers such as PI, PR, deadbeat, and MPC each have limitations in robustness, computational cost, or sensitivity to parameter changes.

This study aims to develop a robust control method for a single-stage single-phase EV onboard charger under uncertain grid impedance conditions. The proposed approach uses an LMI-based robust inner-loop current controller combined with an outer-loop controller for constant current and constant voltage battery charging. The objective is to improve stability, current tracking accuracy, and charging reliability under varying grid conditions.

METHOD

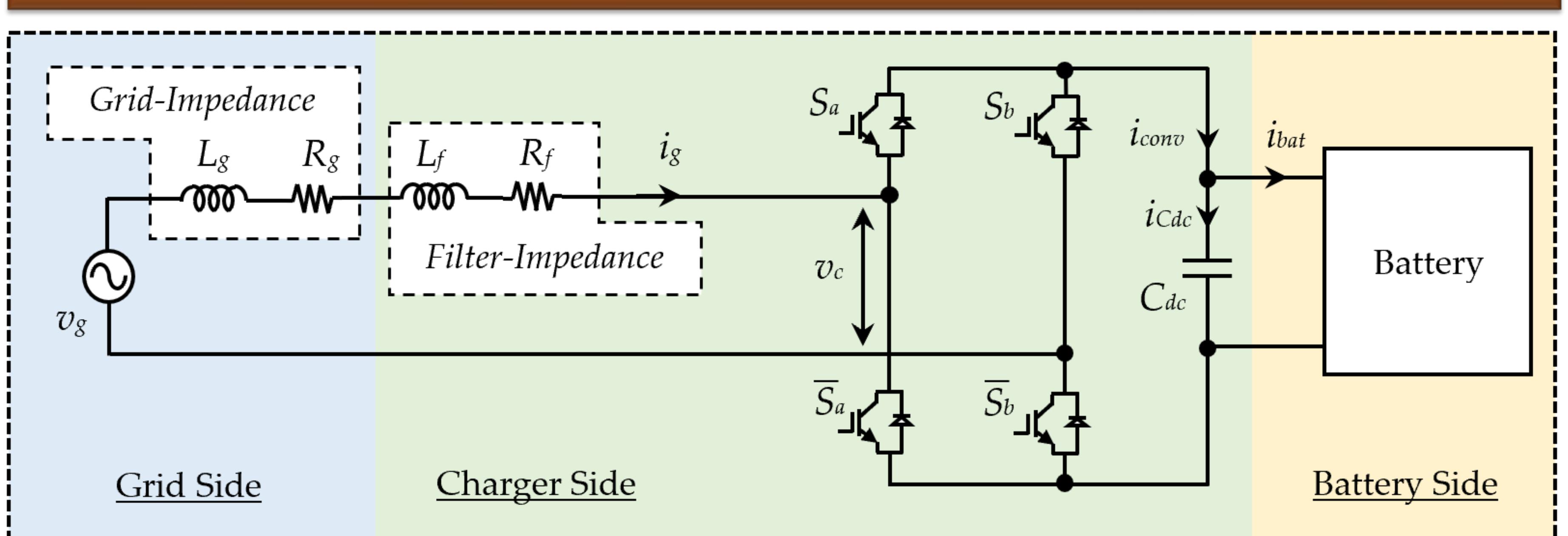


Figure 1. Topology of the single-stage single-phase EV charger including grid impedance and filter components.

System Topology

- Single-phase AC–DC converter using H-bridge active rectifier
- Grid-side filter with uncertain resistance and inductance

Control Structure

- Outer Loop: PI controller regulates DC-link voltage (450 V)
- Inner Loop: LMI robust current controller regulates dq-axis current

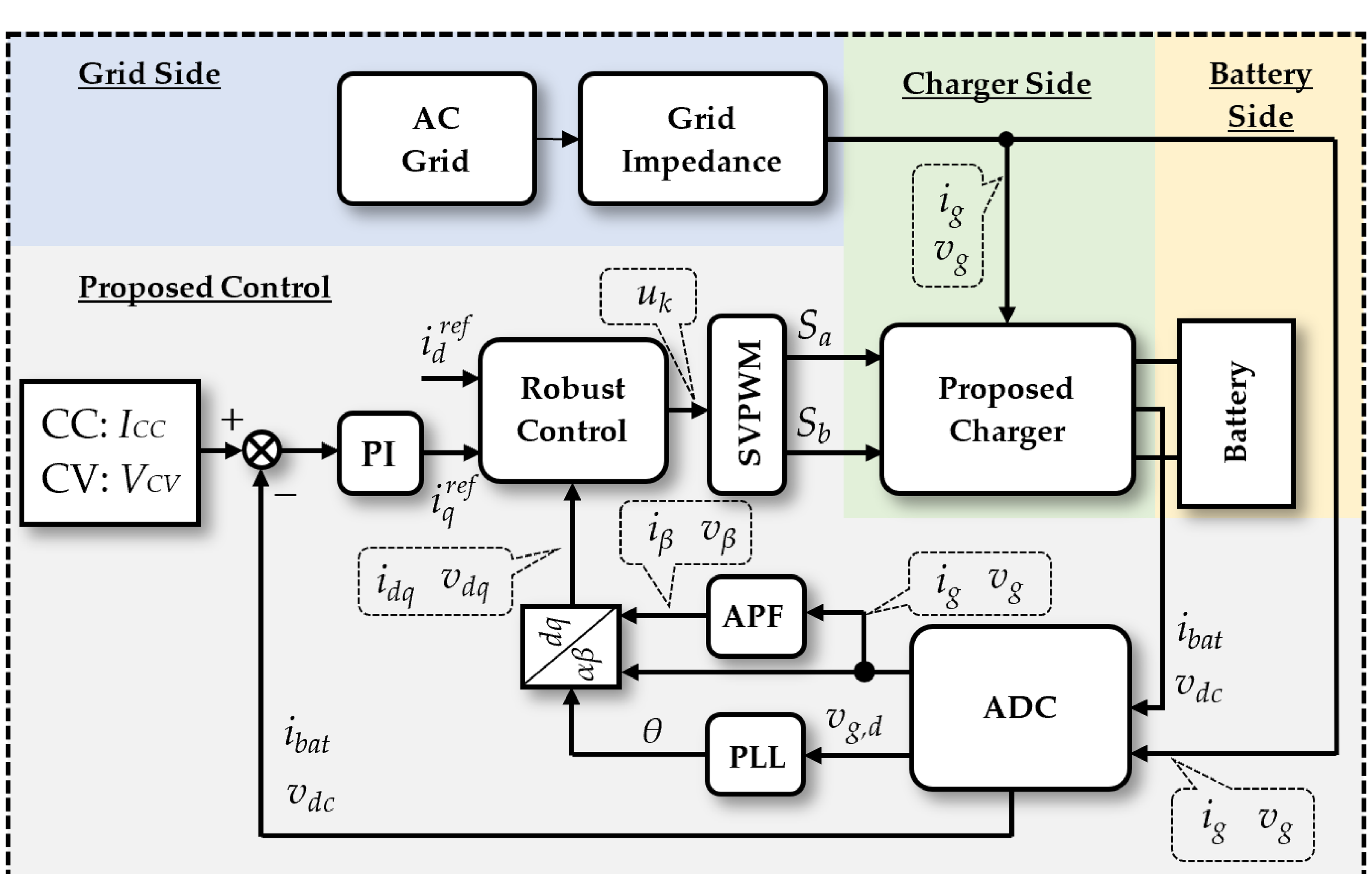


Figure 2. Block diagram of the proposed control structure for the single-stage single-phase EV charger.

RESULTS & DISCUSSION

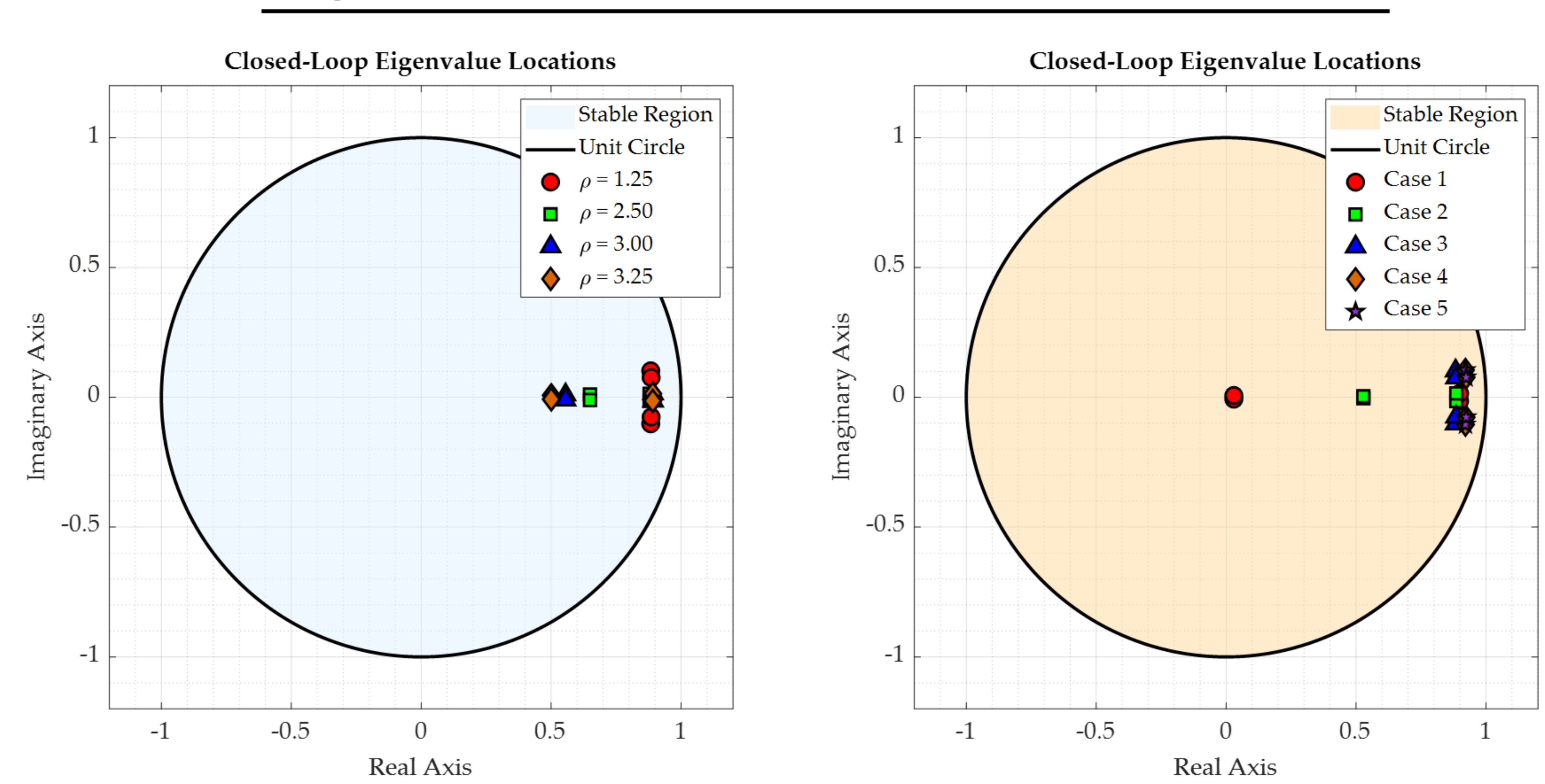
In this section, the simulation results will be illustrated to verify the effectiveness of the proposed controller under various practical conditions with consideration un-certain gird impedance. The controller gains are calculated using the MATLAB soft-ware with the YALMIP toolbox and the PSIM environment. Additionally, the parameters for this simulation studies and case study are presented in Table 1 and Table 2.

Table 1. Simulation parameters of the single-stage single-phase EV charger

Parameter	Symbol	Value
Converter filter inductance	L_f	3 mH
Converter filter resistance	R_f	0.1 Ω
Grid inductance	L_g	4 mH
Grid resistance	R_g	0.1 Ω
Grid voltage (rms)	v_g	230 V
Sampling period	T_s	0.1 ms
Constant-current charging reference	I_{CC}	15 A
Constant-voltage charging reference	V_{CV}	450 V

Table 2. Parameter variations used to evaluate the robustness of the proposed controller

Parameter	Case 1	Case 2	Case 3	Case 4	Case 5
L_f [mH]	0.50	0.75	3.00	4.50	6.00
R_f [Ω]	0.03	0.05	0.10	0.15	0.20
L_g [mH]	1.00	2.00	4.00	6.00	8.00
R_g [Ω]	0.03	0.05	0.10	0.15	0.20



(a) (b)

Figure 3. Closed-loop eigenvalues in the z-plane: (a) eigenvalue locations for different uncertainty levels relative to the nominal system; (b) eigenvalue distribution for uncertainty range ρ = 1.25 under parameter variations.

CONCLUSION

A robust inner-loop current controller was developed for a single-stage single-phase EV charger under uncertain grid impedance. The proposed LMI-based controller guarantees closed-loop stability and reliable current regulation. A digital all-pass filter was used to enable dq-frame control in the single-phase system. Simulation results confirmed strong robustness under parameter variations.

REFERENCES

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