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Toward a robust control approach to the design of power hardware-in-the-loop interfaces

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Abstract : The research project, conducted in collaboration with Hydro-Québec, aims to create a control interface that links real-time electrical grid simulations to renewable energy generation devices for testing purposes. This system will facilitate safe, efficient, and cost-effective testing of these technologies, enabling their integration into the grid and supporting the shift to cleaner energy sources. The design of the interface will leverage the tools of robust control theory to ensure stability and performance despite uncertainties in both the simulated grid and physical devices. After development, it will be validated using Hydro-Québec's infrastructure. This presentation aims to explain how, to date, an interface was designed for nominal operating conditions of the grid and device, and how such a design is insufficient for real-world application.

Toward a Robust Control Approach to the Design of Power Hardware-in-the-loop Interfaces

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McGill GERAD

High-level Problem

- The power hardware-in-the-loop interfacing problem is to synthesize a simulation interface between a grid simulation and a power-generating device.
- The interface must be transparent, in that the grid-interface-device interconnection must mimic the reference grid-device interconnection, even in the presence of modelling uncertainty.

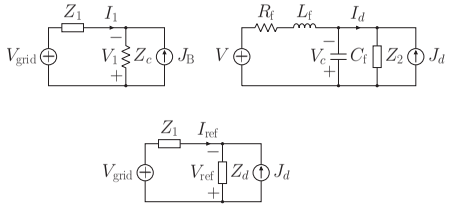
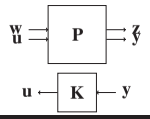


Figure 1: Linear circuit models of the grid simulation or rest of system (ROS, top left), power amplifier and device under test (DUT, top right), and reference system (REF, bottom).

- Upon successful synthesis of such an interface, a powerful testbed for renewable energy-generating devices becomes available to simulate at low cost the integration of such devices into the grid.

Methodology and Results

- Existing solutions to this problem include the ideal transformer method [1] and the transmission line method [2].
- Both of the above solutions are special cases of the generalized control framework [3].
- In this application, **P** is an appropriate combination of the DUT and ROS systems, as well as delays.
- The exogenous inputs **w** are V_{grid} and J_d.
- The control objectives **z**, which must be bounded or driven to zero in the steady state, are $V_1 - V_c$ and $I_1 - I_d$, weighted according to given performance specifications.
- The measurements are appropriately delayed versions of V_1, I_1, V_c, and I_d.
- The interface-generated actuation signals are V and J_{B}.
- The interface **K** is synthesized using either one the analytic equation-based or convex optimization-based formulations.



Methodology and Results (continued)

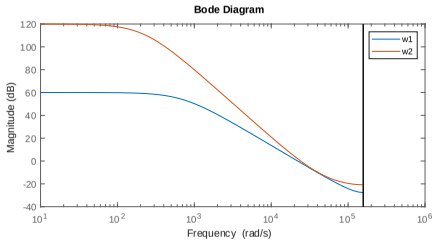


Figure 3: The magnitude response of the weights encoding the performance specifications.

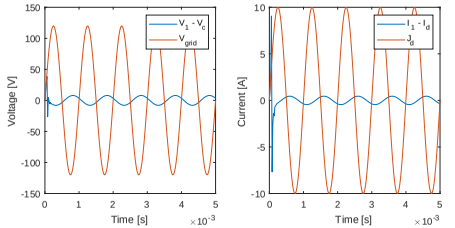


Figure 4: The time domain response of the grid-interface-device interconnection.

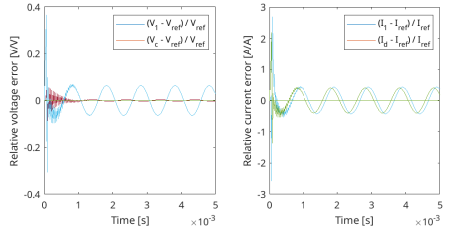


Figure 5: A comparison of the time domain responses of the grid-interface-device interconnection and the reference model. The synthesized interface is not quite transparent, which reveals a flaw in the control problem statement.

Low-level Problems and Project Direction

- The performance of the interface is guaranteed only for nominal operating conditions of the ROS and DUT
- Very poor, almost nonexistant robustness guarantees built into this particular interface
- Existing techniques to impose robustness onto the interface are only able to handle bounded modelling uncertainty [4].
- For the problem to be solved successfully, extreme operating conditions, presenting unbounded levels of modelling uncertainties, must be handled as well.
- As evidenced by Figure 5, the interface synthesized using the straightforward generalized control framework is not transparent.
- The objective of making ROS and DUT signals mimic each other seems to be an inadequate formulation of the problem.
- The generalized control problem generalizes the existing solutions in an unstructured way, but that seems to yield a hyper-sensitive focus on performance and no robustness.

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