

DynConGrid and GridForge: From Co-Design to Adaptive Operation for Resilient Power Grids

Ph.D. Project Proposal

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Introduction

The transition toward renewable energy profoundly changes how power systems must be operated and designed. Increasing variability from solar and wind generation and more dynamic consumption patterns require the grid to become both **more flexible** and **more intelligent**.

This project combines two complementary research directions—**DynConGrid** and **GridForge**—to produce an integrated framework for co-design and adaptive operation of electrical networks. **DynConGrid** develops real-time Model Predictive Control (MPC) for congestion management by reconfiguring topology, curtailing generation, and dispatching storage. **GridForge** designs the network itself so that it supports a **catalog of feasible, stability-certified topologies**. During design, surrogate/proxy models approximate MPC outcomes, enabling the evaluation of how operational controllers behave under candidate topologies and thereby optimizing total cost (CAPEX + OPEX). The two topics are tightly coupled: DynConGrid supplies behavioral data and models; GridForge uses them to certify and select topologies that guarantee safe, efficient, distributed operation.

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Scientific Context and Originality

Traditionally, congestion management relied on preventive planning, redispatch, and curtailment under fixed network topologies. Over the past decade, Sorin Olaru and collaborators developed MPC-based congestion management and distributed control tools that account for storage and curtailment [1, 2, 3]. These works motivate extending MPC with discrete topology choices (switching) to exploit structural flexibility.

Ye Wang’s recent contributions are directly relevant: real-time distributed MPC with limited communication rates and optimization-based network partitioning point to scalable, communication-aware control designs; stochastic MPC and co-design studies demonstrate methods for handling uncertainty and jointly optimizing assets and controls [4, 5, 6, 7]. The originality of this combined project lies in bridging design and operation: (i) extending MPC to include topology reconfiguration in a computationally tractable way (DynConGrid); and (ii) integrating surrogate models that emulate MPC-driven operational outcomes, allowing GridForge to select topology sets minimizing total cost while guaranteeing fast-dynamics stability and distributed control compatibility.

Objectives and Methodology

DynConGrid (Adaptive Operation)

- Formulate MPC combining continuous controls (curtailment, storage) and discrete topology switching.

- Develop scalable solvers and heuristics (relaxations, decomposition, learning-assisted policies) for near-real-time computation.
- Incorporate uncertainty from renewable generation and demand using robust and stochastic MPC; minimize expected *operational cost* (OPEX).

GridForge (Co-Design and Flexibility)

- Generate candidate network topologies and switching patterns to define a broad design space.
- Simulate DynConGrid across representative scenarios to obtain operational-cost and performance data.
- Develop **surrogate/proxy models** that approximate MPC outcomes (control actions, costs, constraint margins), enabling exploration of many topologies efficiently during design.
- Formulate a co-design optimization minimizing total cost = CAPEX (assets) + expected OPEX (MPC-driven operation), under stability and locality constraints.
- Apply control-theoretic certificates (Lyapunov, passivity, input–output) to guarantee fast-dynamics stability for all topologies retained in the feasible catalog.

The surrogates are not merely computational shortcuts—they are essential to include the effects of MPC-based operation during design, ensuring that the selected grid flexibility reflects realistic control behavior and total cost. Their definition will require strong collaboration between DynConGrid and GridForge.

Expected Results and Perspectives

- A mixed-integer MPC operational framework allowing topology reconfiguration for congestion management (DynConGrid).
- Surrogate-based co-design tools capturing MPC-driven operation, enabling scalable exploration of flexible topologies (GridForge).
- A certified set of feasible, stability-guaranteed topologies that balance CAPEX and expected OPEX.
- Methodological advances in surrogate-assisted optimization, distributed MPC, and stability certification.

This research bridges grid planning and real-time operation, offering operators a pathway to resilient, adaptive, and cost-efficient renewable-rich grids.

Relation to PIs' Research Themes

Sorin Olaru: Expertise in predictive and distributed control, constrained optimization, and stability certification directly supports the development of MPC formulations with topology switching and the derivation of stability certificates for flexible topologies.

Ye Wang: His work on distributed MPC, network partitioning, stochastic MPC, and co-design of control and infrastructure provides essential methods for scalable control, surrogate development, uncertainty handling, and cost co-optimization [4, 5, 6, 7].

Patrick Panciatici (Industry Advisor): Provides industrial insight and validation, ensuring practical feasibility and alignment with real-world grid operation and planning practices.

References

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