

## **Advanced Model Predictive Control Techniques in Real-time Operations and Control of Power Systems**

Model-based network-wide optimizations in real-time emergency control of power systems are largely bottlenecked by the fast computational requirements. Furthermore, the operational aspects of modern power and energy systems are going through transformative changes to tackle global renewable energy expansion-related issues. Decentralized operations in power systems are becoming essential with the influx of distributed energy resources (DERs), dynamic loads, and electric vehicles (EVs). This research considers a well-known model-based strategy, Model Predictive Control (MPC), for real-time operation and controls of power systems and proposes novel methods utilizing machine learning, data-driven methods, and operator theory to solve computational challenges by making those real-time for the first time. Additionally, we develop a distributed MPC framework to address the recent needs of power systems' operation and control.

In Part I, we first present a machine learning (ML)-accelerated MPC implementation in emergency voltage control problems. This method computes an optimal control strategy for the nominal system model offline and performs successive online control corrections at each control instant to adapt the offline computed controls for real-time scenarios. In the online phase, the required voltage trajectory prediction, and its sensitivity computation to control inputs are achieved by machine learning-based approaches, thereby accelerating the overall control computation multiple times. Next, we present an alternative data-learned linear Koopman embedding approach for model predictive emergency voltage control in a power grid. This approach involves a "basis-dictionary free" method to lift the nonlinear power system dynamics to a higher dimensional linear space where MPC is exercised in a real-time fashion. We propose a novel data-driven encoder-decoder architecture, Koopman-inspired deep neural network (KDNN), which supports end-to-end learning from trajectory data. The MPC optimization in linear space makes the problem scalable and rapid for real-time implementations.

Part II of this research focuses on distributed MPC design for quasi-static power flow-based voltage control problems under short-term (15 minutes) variations of load and generation profiles. To realize the proposed distributed control, first, a centralized voltage control problem assuming grid observability is formulated and next transferred to the distributed versions based on both bus-wise and area-wise decomposition of the network. Distributed versions are solved via the alternating direction method of multipliers (ADMM), utilizing only neighbor-to-neighbor communications to attain optimal solutions.

The implementation, efficacy, performance, and robustness of proposed research approaches are validated with IEEE test system benchmarks.