Computationally Efficient Stochastic Model Predictive Control for Smart Grid Applications

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Context

Humanity is facing a climate challenge of unprecedented magnitude. Pursuing the goal of carbon neutrality implies developing new solutions. Thermal power plants are increasingly replaced by renewable sources. Massive installation of wind and solar energy systems leads to an increasingly complex regulatory and economic environment. Wind and solar resources are not constantly available and predictable. Hence they disrupt the conventional control methods for planning the daily operation of the electrical grid. Their power fluctuates over multiple time horizons, forcing the grid operator to perform real-time operating procedures. A solution to improve the electrical grid stability is to use storage systems in residential homes. Forecast based operation strategies of these systems are deployed to integrate more renewables into the electricity system. However, wind/solar resouces as well as electrical load on site are subject to forecast uncertainties decreasing the control system's performance.

Objectives

In this postdoc, we aim to study a new computationally effcient control scheme using a model of forecast uncertainties. The studied systems are set in a residential context where the financial margins are slim. To target the problem, it is shown in several studies [1], [2] that stochastic model predictive control (SMPC) is a promising solution. SMPC outperforms comparable heuristic and deterministic optimization-based control schemes. The strength of MPC lies in the use of a mathematical model of the smart grid system to predict its future behavior. Using these predictions, MPC can optimally select the control actions based on a given objective while taking into account the constraints, and wind/solar, eletrical load forecasts in a systematic and flexible way.

Despite the abundance of research papers, MPC is still in its early stage for smart grid control. This is because the computational complexity of SMPC is very important especially for medium/large size systems. It is well known that the SMPC optimization problem can be formulated as a second order cone program (SOCP). The traditional way to solve a SOCP problem is to employ a primal-dual interior point method (IPM), which has attractive polynomial time complexity. However, the IPM requires sophisticated and heavy computational tasks to be performed at each iteration, for example, solving Newton's type systems. For real-time embedded SOCP problems, a single iteration of such a polynomial time algorithm is often too expensive to be of practical use. Hence, the classical way to tackle the SMPC problem is to combine the scenario-based approach with the quadratic programming (QP). In the result, a very large scale QP problem that needs to solve online is obtained.

In this postdoc, we will follow the SOCP approach. To avoid the high online computational complexity of the primal-dual interior point method, we will use the first-order splitting approaches, similar to the one that was recently proposed in [3] for the quadratically constrained quadratic program. The main idea is to exploit the inner structures of the optimization problem.

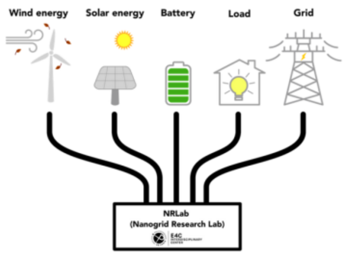
Methods

The postdoc consists of 3 phases.

In Phase 1, we aim to design a stochastic centralized MPC algorithm. The main purpose here is to analyze the tradeoff between the performance and the computational complexity of the SMPC. In this phase, we will also propose a SOCP solver for the MPC optimization problem.

In Phase 2, we aim to design the stochastic distributed MPC algorithm. We will also consider the problem of implementing a SOCP solver in embedded systems. This is generally a challenging due to the low computational and memory resources of the embedded systems. The results in Phase 1 will be used to take advantages of inner structures of the optimization algorithms.

In Phase 3, we aim to validate the proposed methods in the NRlab.



Expected Results

+) A SOCP Matlab/Simulink Toolbox.
+) A demontration of a real time implementation of the stochastic distributed MPC algorithms in a low-cost microcontroller/microprocessor.
+) A comparison between the new methods and currently used methods.

References

[1] Hooshmand, A., Poursaeidi, M. H., Mohammadpour, J., Malki, H. A., & Grigoriads, K. (2012, January). Stochastic model predictive control method for microgrid management. In *2012 IEEE PES Innovative Smart Grid Technologies (ISGT)* (pp. 1-7). IEEE.

[2] Zhu, D., & Hug, G. (2014). Decomposed stochastic model predictive control for optimal dispatch of storage and generation. *IEEE Transactions on Smart Grid*, *5*(4), 2044-2053.

[3] Hoai-Nam Nguyen, « *Improved Prediction Dynamics for Robust MPC* », IEEE Transaction on Automatic Control, 2022.