Scalable Predictive Control and Optimization for Grid Integration of Large-scale Distributed Energy Resources

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Motivation & Introduction

- Distributed Energy Resources (DER) with controllable power set-points, e.g., photovoltaics (PVs), energy storage systems (ESSs), electric vehicle supply equipment (EVSE), buildings with heating, ventilation, and air conditioning units (HVACs), are expected to be a large part of the future power grid
- These DERs could potentially offer flexibility to the larger transmission system and its associated market, if integrated together in a controlled and coordinated fashion
- Controlling many DERs with inter-temporal constraints (such as ESSs, EVs, and buildings) and periodic variations (such as PVs) requires look-ahead formulations with fast evaluation of the control algorithm that coordinates the DERs and market signals (price, economic dispatch, or automatic generation control signal).
- Existing studies for integrating DERs either do not consider a look-ahead period, or are conducted on a small scale, i.e., tens of devices
- **We propose a look-ahead optimization formulation which can control thousands of DERs utilizing a variable time granularity formulation of the optimal control problem**

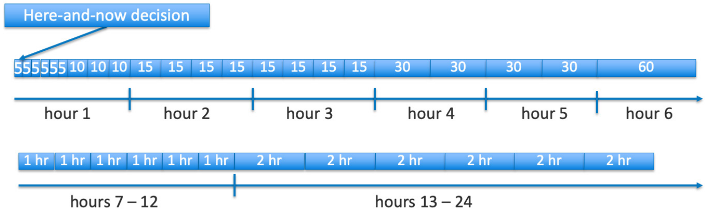

Fig 1. Variable granularity implementation of the proposed look-ahead controller

Proposed Control Approach

- We consider variable time granularity where time steps near the control horizon have finer time resolutions (5 minutes), and those further in the future have coarser time resolutions, up to 2 hours (see Figure 1)
- The MPC-based controller solves each optimization problem in successive five-minute time steps
- Optimization formulation includes:
  - Real power-balance constraints
  - Feeder-head power injection/withdraw at locational marginal price (LMP)
  - ESS charging/discharging with state-of-charge management and mileage costs
  - PV power generation & curtailment
  - Building model, including HVAC heating/cooling complementarity, building thermal dynamics, and indoor temperature comfort
  - EV charging station with aggregate power and energy requirements
  - Minimization of total cost

Case Study

- Two sample distribution systems – a small-scale example with 50 devices, and a large-scale example with 2507 devices, including curtailable PVs, ESSs, buildings with HVACs, and EVSEs.
- Control problem is formulated as a mixed-integer optimization problem and solved with XpressMP
- Proposed control policy (MPC1) is compared against two similar MPC-based policies:
  - MPC2: Uniform 5-minute time granularity and a 24-hour look-ahead horizon
  - MPC3: Uniform 5-minute time granularity and a 3-hour look-ahead horizon

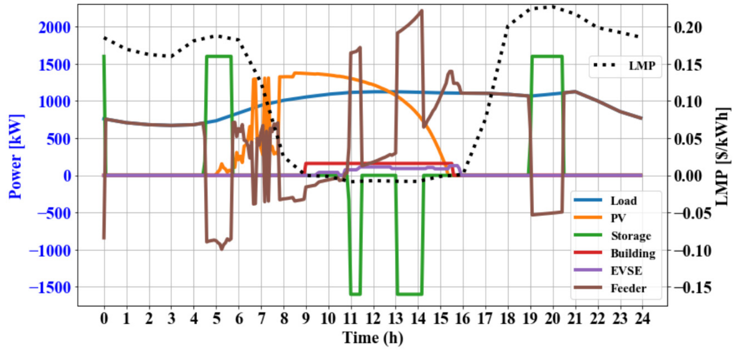

Fig 2. Aggregate dispatch profile for each device type (left) and the LMP signal (right)

Simulation Results

- Simulated a day of operations – 288 problems total, once every 5 minutes
- Figure 2 shows the overall performance of the MPC-based control approach, which manages to shift demand from when it is expensive to when it is inexpensive
  - Controller injects power during the morning LMP peak at 5:00 and the evening price peak at 19:00, while withdrawing power at the LMP nadir near 11:00 and 13:00
  - Building and EVSE dispatch is moved to times when LMPs are near $0/kWh

Table 1. Performance Comparison – Distribution System with 50 Controllable DERs

Controller (time step / horizon)	Total Operating Cost ($)	Mean Computation Time (sec)
MPC1 (variable / 24 hours)	420.5627	0.9856
MPC2 (5 min / 24 hours)	420.2215	5.4049
MPC3 (5 min / 3 hours)	430.2215	0.6272

Performance Comparison

- In the small test system (50 devices, Table 1):
  - MPC1 achieves similar operational cost as the more-ideal MPC2 (<0.1% difference)
  - Has a similar computational burden as the higher-cost MPC3
- For the large test system (2507 devices, Table 2):
  - MPC2 needed 29 minutes to complete the first control step, removing it from consideration
  - MPC1 achieves a ~16% reduction in cost over MPC3, with a modest increase (42%) in computational time, while still well within the 5-minute control step duration
  - Total operating cost is negative – load shifting, storage arbitrage, along with negative LMPs

Table 2. Performance Comparison – Distribution System with 2507 Controllable DERs

Controller (time step / horizon)	Total Operating Cost ($)	Mean Computation Time (sec)
MPC1 (variable / 24 hours)	-567.4760	209.51
MPC3 (5 min / 3 hours)	-488.3263	146.78

Conclusions

- Large numbers of DERs can effectively be controlled utilizing off-the-shelf MIP technology when care is taken in the look-ahead formulation
- Coarser time granularity in the time periods in the medium term do not hurt operational performance but significantly improve computational performance

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