# Model Predictive Control of Industrial Loads and Energy Storage for Demand Response


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## Introduction

- Demand response demonstrates potentials to enhance the power system's operational flexibility in a cost-effective way.
- Advantages of Industrial Loads in DR
  - **Infrastructure**: Most industrial loads have already installed the infrastructures for control, measurement, and communications which are necessary for demand response.
  - **Response**: The adjustments of the power consumption from many industrial loads can be very large, fast, and accurate.
  - **Economic Incentive**: The industrial loads are also strongly motivated to participate in demand response programs even at the cost of increasing their operation complexity, as making profits is their primary concern.
- Examples
  - smelting pots, furnaces, fans, freezers, pumps, mills, crushers, etc.
- Challenges for Industrial Demand Response
  - reliability, complexity, granularity
- Granularity Restriction
  - Most of these industrial loads can only provide power changes in a discrete manner, e.g. the power change is several MWs at a time.
  - This coarse granularity hinders those industrial loads from providing the most valuable ancillary services, as regulation and load following in the current electricity markets require a continuous change of power.
- **Research Objective**
  - **Fully utilize the DR potentials from the industrial loads.**
  - **Overcome the granularity restriction.**

## Coordination by Model Predictive Control

- Main Idea: support by on-site energy storage
  - industrial machines: **large/discrete** power change, **main body**
  - on-site storage: **fine/continuous** power change, **handle mismatch**

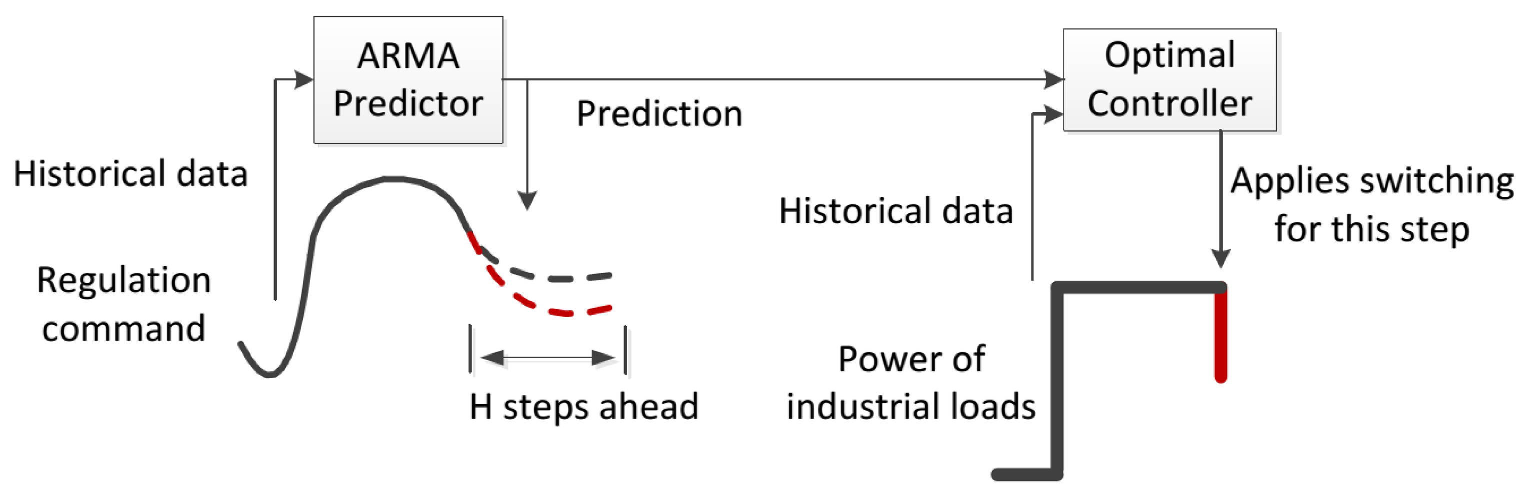


Figure 1: MPC coordination framework.

## Prediction

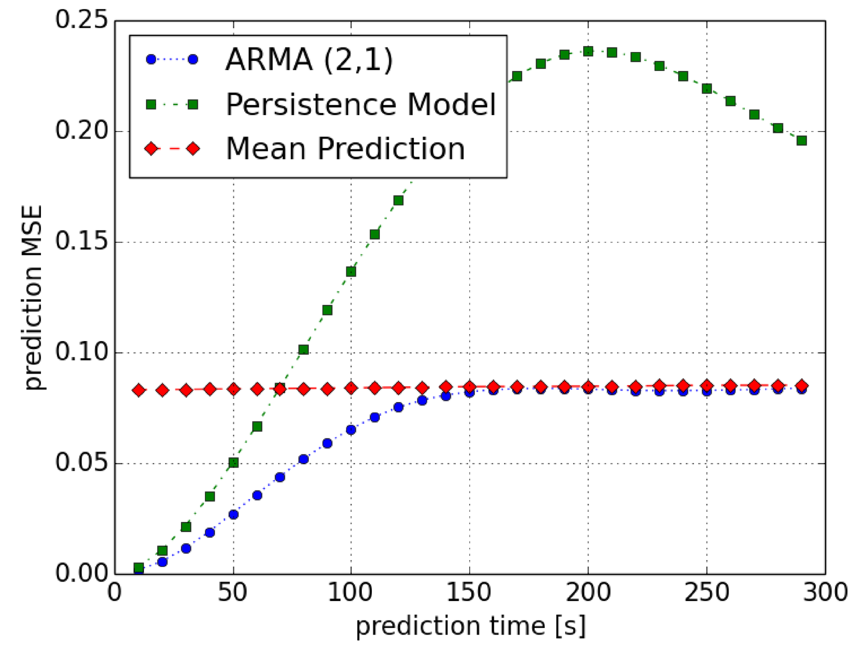


Figure 2: Prediction mean squared errors.

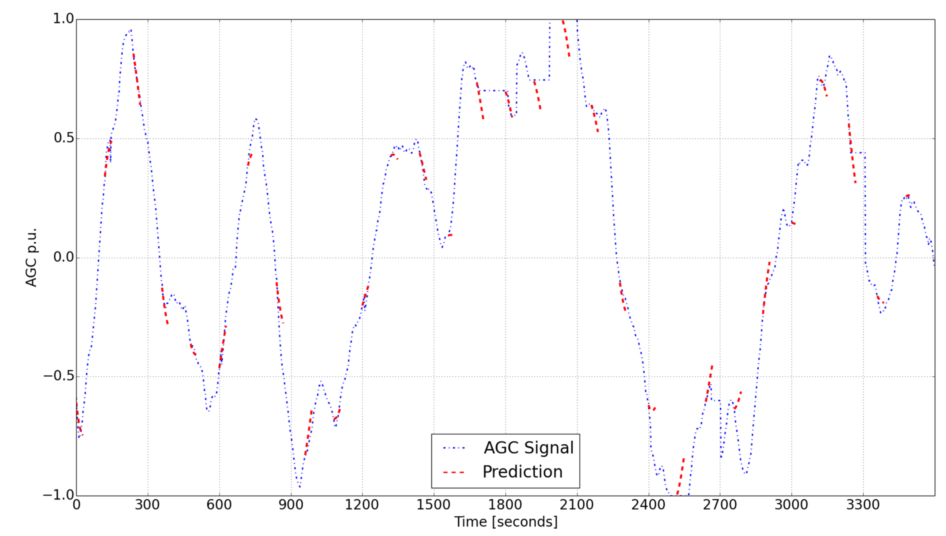


Figure 3: Regulation signal (AGC) over one hour and its prediction.

## Optimal Control

- Objective
$$\text{minimize} \quad \sum_{i\in H} (\alpha v_i + \beta s_i) + \gamma d \tag{1}$$
- Regulation Violation
$$v_{t+i} \geq |B + R\widehat{\omega}_{t+i} - P_m x_{t+i} - y_{t+i}| \quad \forall i \in H \tag{2}$$
- Machine Switching
$$s_i \geq |x_{t+i} - x_{t+i-1}| \quad \forall i \in H \tag{3}$$
- Storage Level Deviation
$$d \geq |e_{t+H} - \overline{e}| \tag{4}$$
- Storage Energy Balance
$$e_{t+i} - e_{t+i-1} = y_{t+i}\delta \quad \forall h \in H \tag{5}$$
- Switching Limitation
$$\sum_{j=t+i-L}^{t-1} \widetilde{s}_j + \sum_{j=t}^{t+i} s_j \leq \overline{s} \quad \forall i \in H \tag{6}$$
- Variable Ranges
$$x_{t+i} \in \{0,1,\dots,n\} \text{ and } -P_s \leq y_{t+i} \leq P_s \quad \forall i \in H \tag{7}$$

## Case Study

- Simulation Setup
  - industrial machines: 4*2MW
  - on-site storage: $E = 1$ MWh, $P_s = 3$ MW
  - provide regulation $R = 6$ MW at baseline $B = 4$ MW
- Result
  - accurately provide a large range of regulation
  - over the hour: only 12 switches and 0.12 MWh violation integral

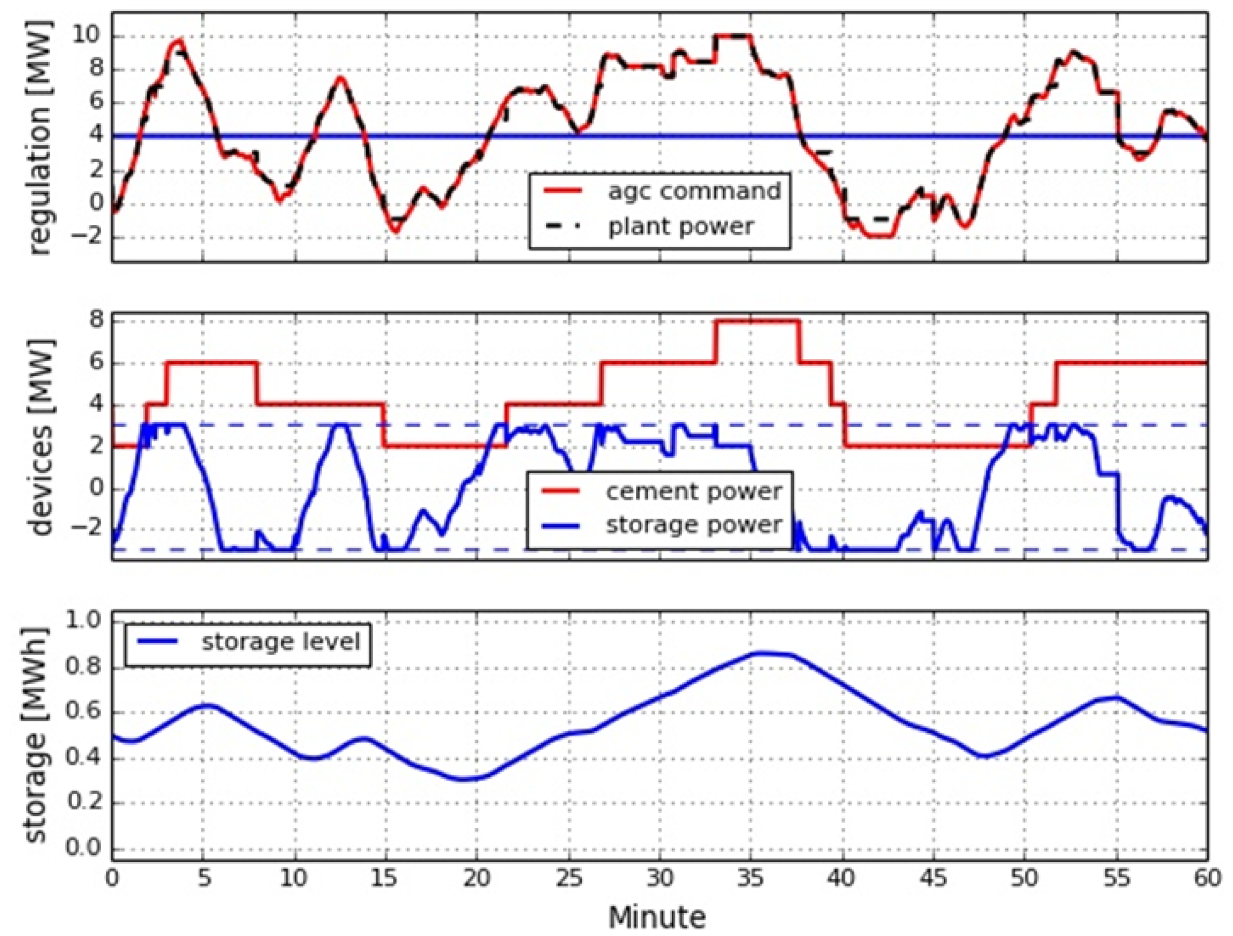


Figure 4: Simulation results with increased penalty on switch actions.

## Conclusion

- Fully Utilize Industrial Loads' DR Potentials
  - add more balancing resources to power system
  - encourage loads to be more active in DR
- MPC Coordination Framework
  - "the whole is greater than the sum of its parts"
  - many potential applications
    e.g. the coordination among fast/slow generators, buildings, storage, ...


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- Relevant work available at http://www.xiaozhang.work/