Unlocking the Market Value of Energy Storage via Improved Economic Dispatch and Storage Control

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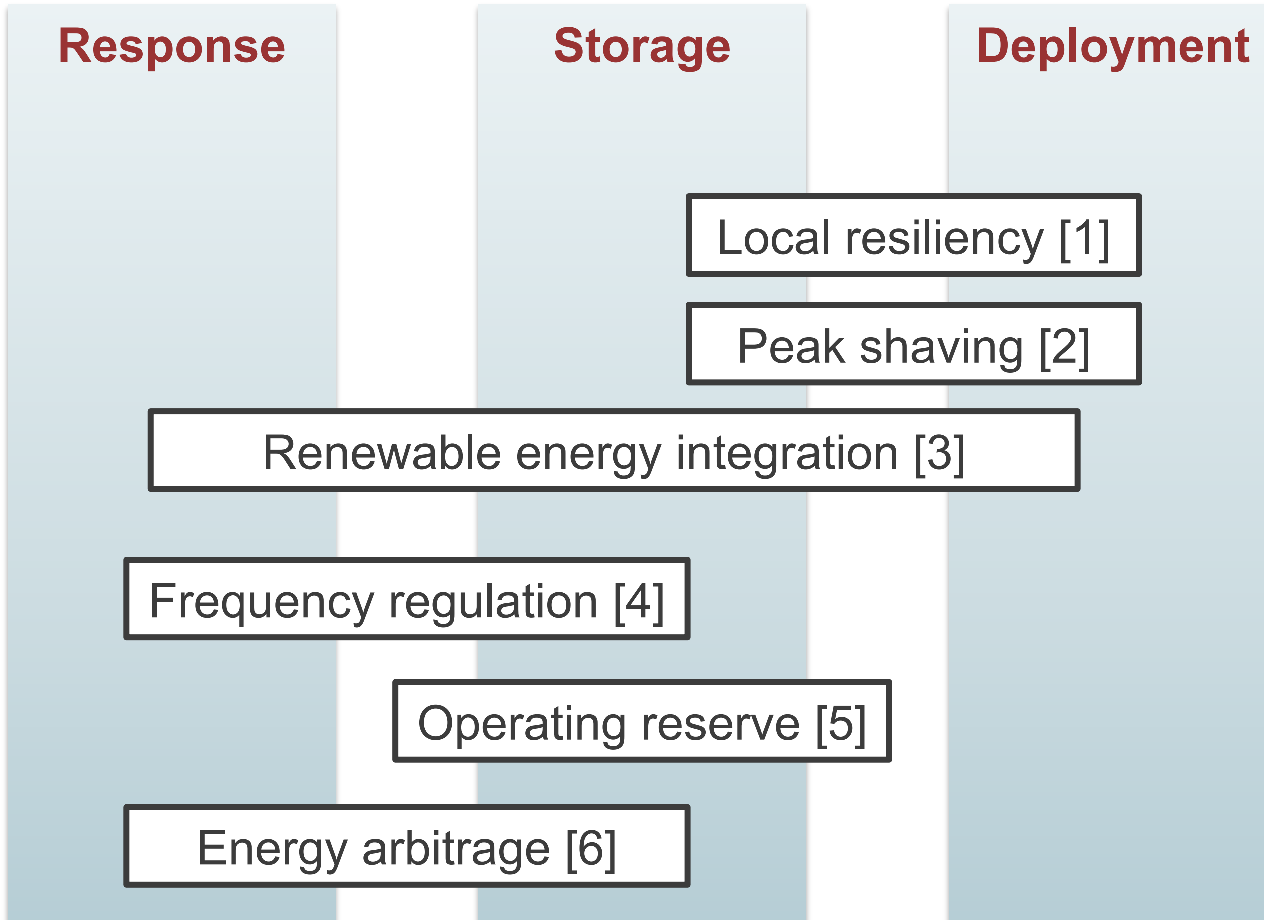
Value of Energy Storage in Power System



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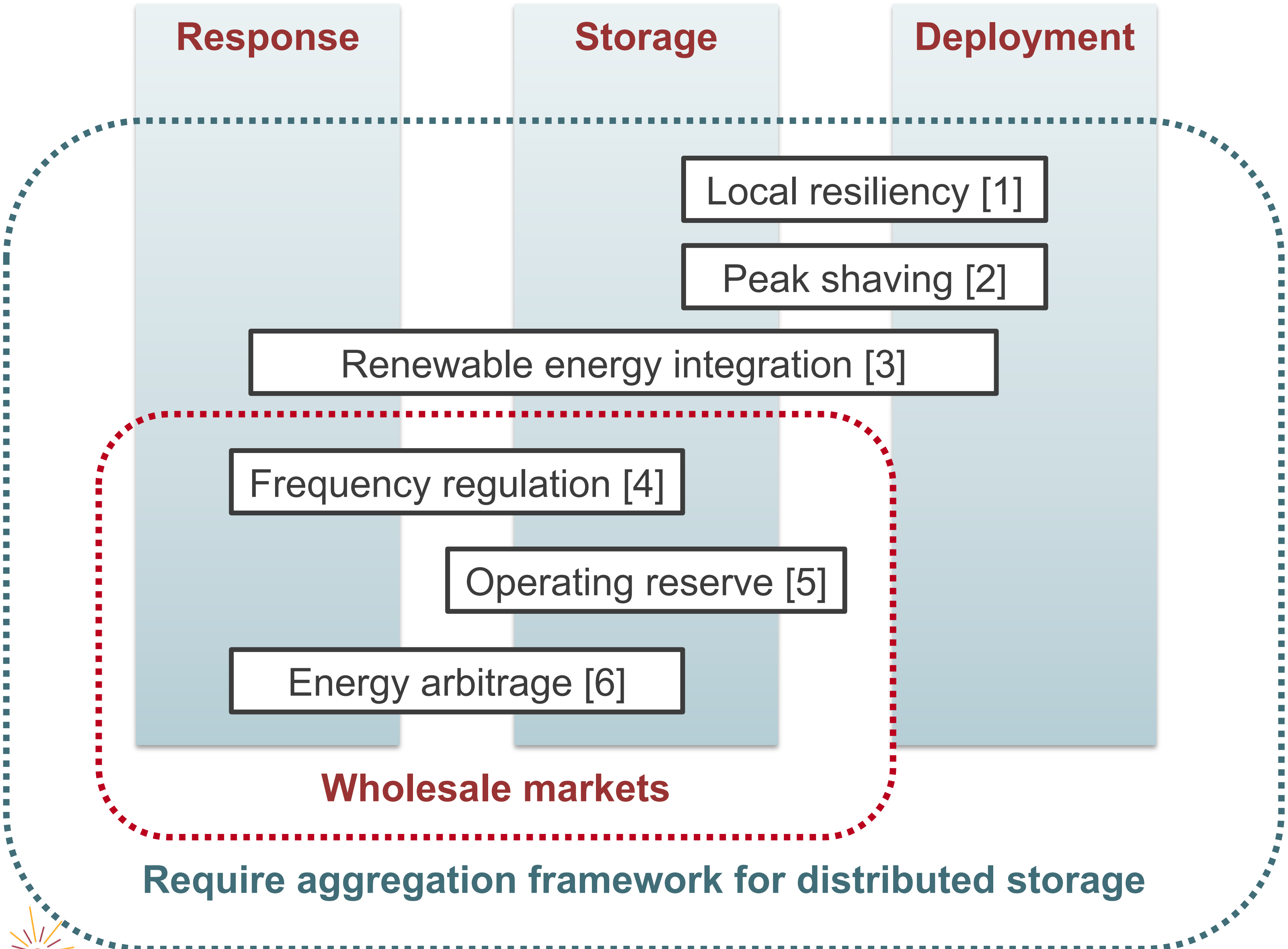
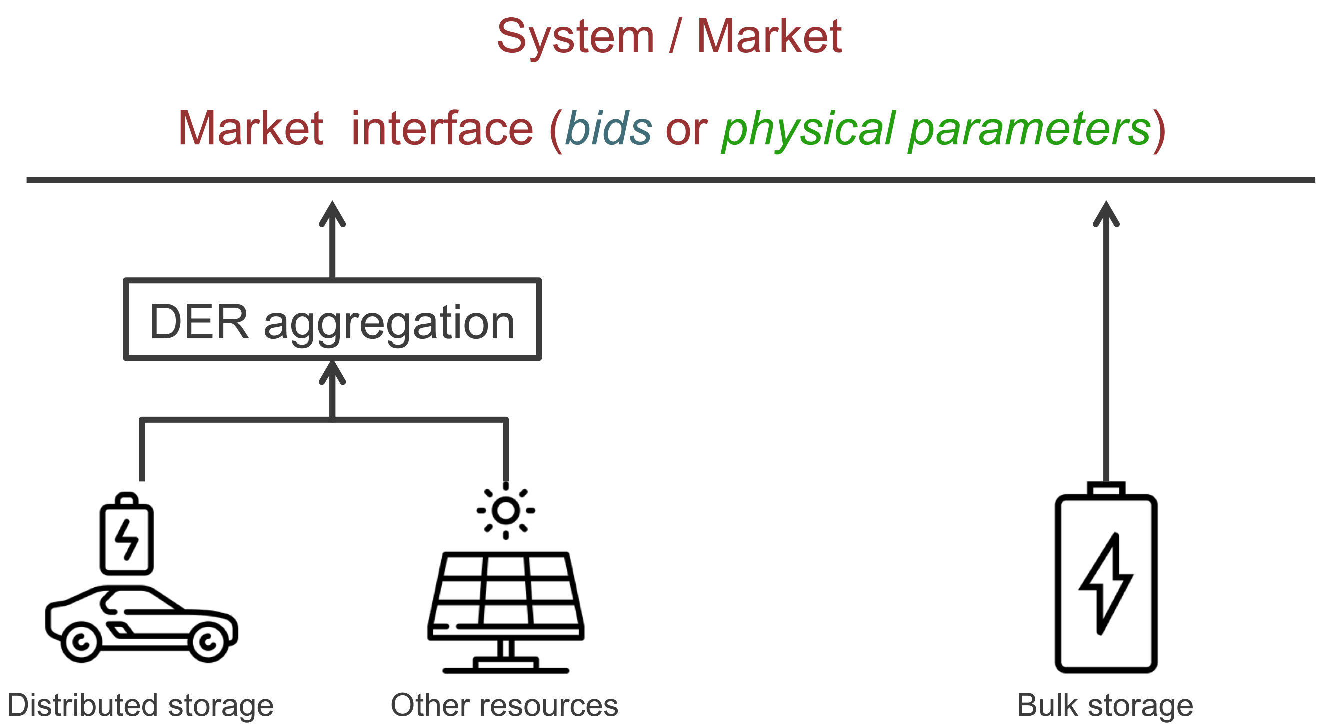
Value of Energy Storage in Power System



Interaction between Energy Storage and Market



Challenges

- Solving large-scale multi-period dispatch optimization
- Plug-and-Play for DER aggregation

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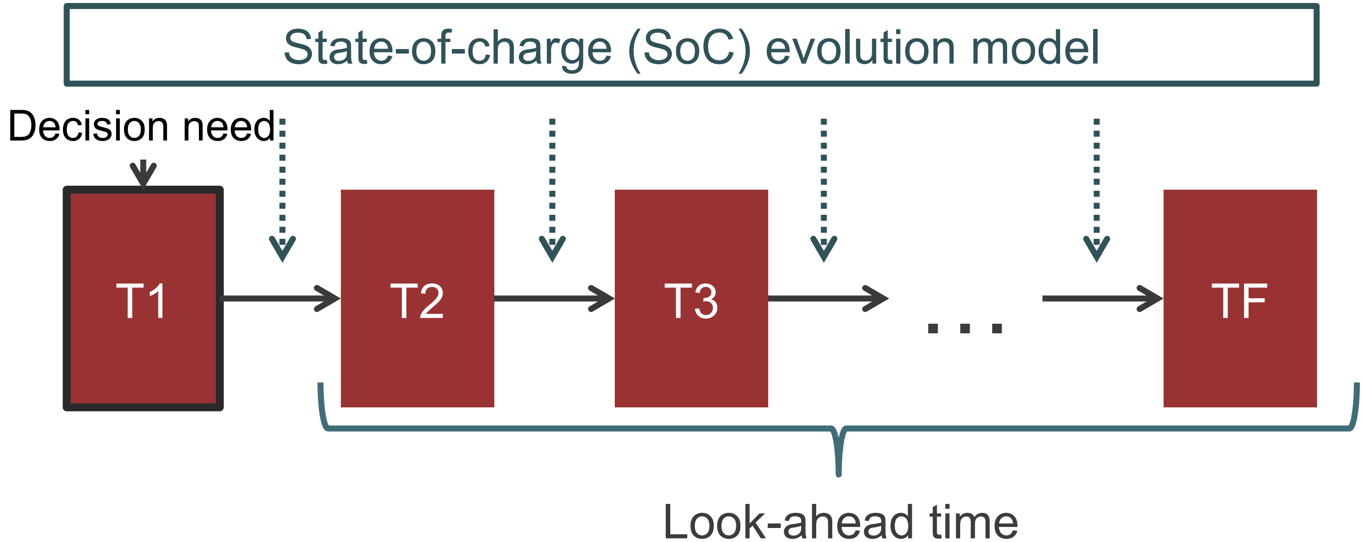
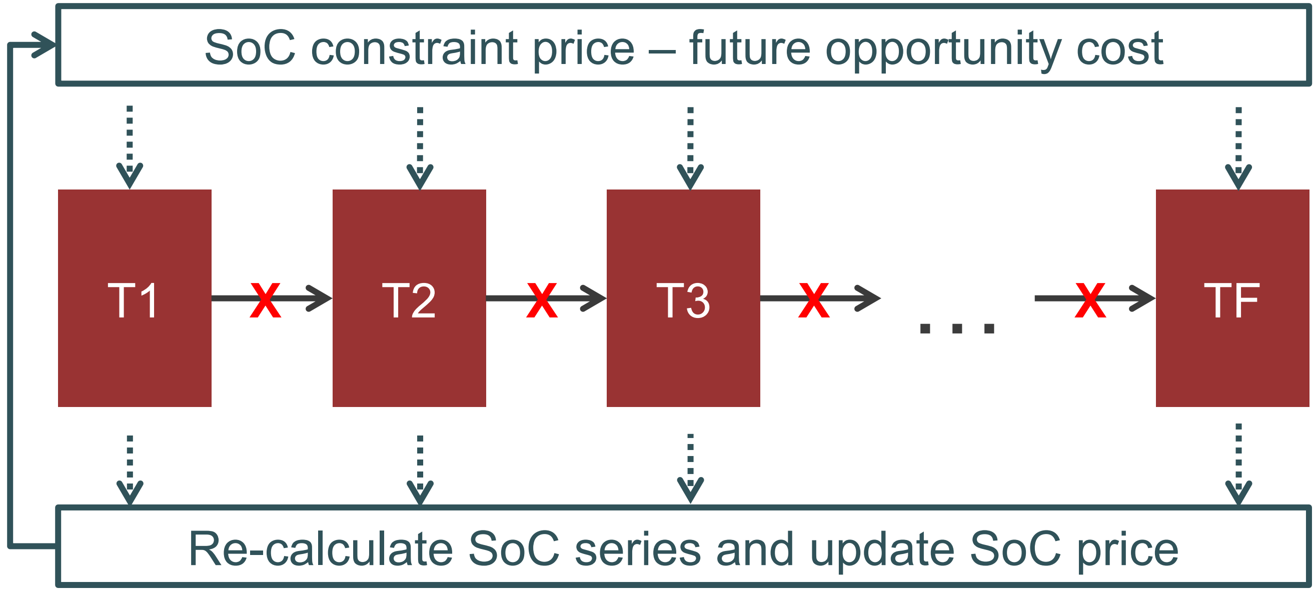
Solving the Optimization Problem



Require commercial optimization solver
Solution time increases with problem size

- Consider
  - Charge and discharge efficiency
  - Power and energy rating
  - Operating cost
  - End state-of-charge level (EV)

Solving the Optimization Problem via Dual Decomposition



- Extremely fast computation speed and parallelizable implementation
- Solves single-storage problem to optimal (no other solver needed)
  - Degradation model
  - Stacked services

Multi-period look-ahead control formulation

$$p_1^* \in \arg\min O_1(p_1) + O_2(p_2) + \cdots + O_T(p_T) + C(e_T)$$

Current info. — Look-ahead — End-state cost

Subjects to power and energy ratings

State-of-charge (SoC - e_t) evolution constraint with efficiency (η):

SoC change = - Discharge + Charge

$$e_t - e_{t-1} = -[p_t]^+/\eta + [-p_t]^+\eta$$

Single-Storage Solution Algorithm

Optimal policy: $p_t^* = p_t^\pi(\theta_{t-1})$, closed-form → $p_1^* = p_1^\pi(\theta_0)$

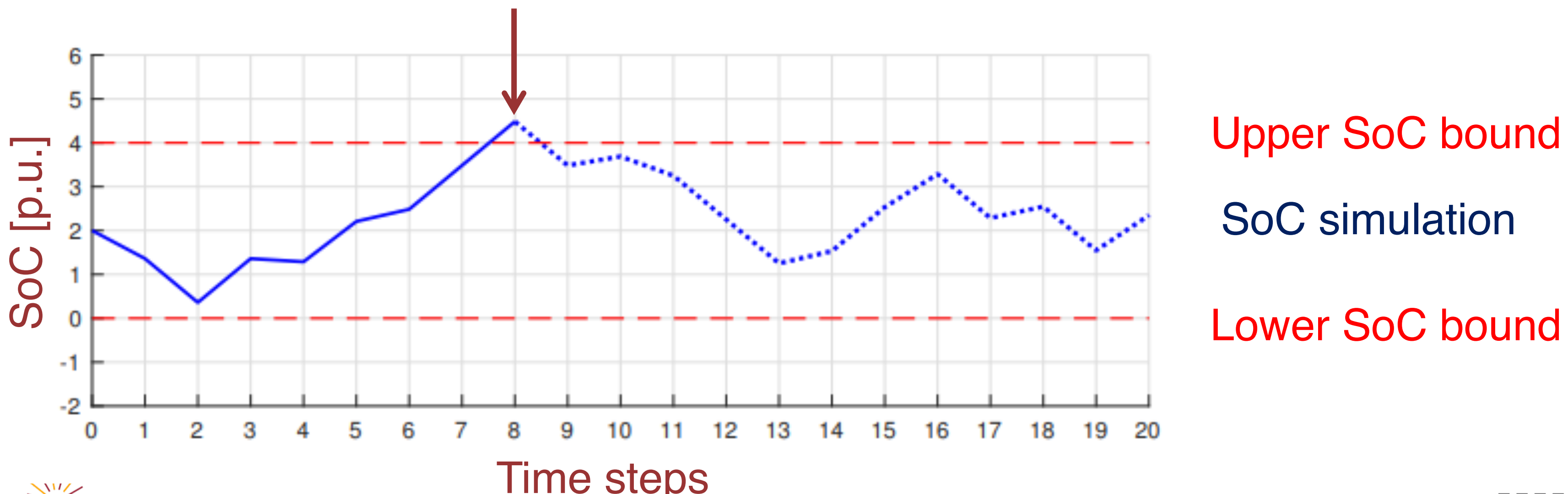
θ_0 is the Lagrangian dual – opportunity value of energy left in the battery

$$\theta_0 : \; e_1 - e_0 = -[p_1]^+/\eta + [p_1]^-\eta$$

Find θ_0 via Binary Search Algorithm, start by picking a random $x \in R$

Simulate control $p_1^\pi(x)$ and check SoC e_t

- **If** reached upper SoC bound **then** $x \geq \theta_0$



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Simulate control $p_1^\pi(x)$ and check SoC e_t

- **If** reached upper SoC bound **then** $x \geq \theta_0$
- **If** reached lower SoC bound **then** $x \leq \theta_0$
- **Otherwise**, check with end-state function

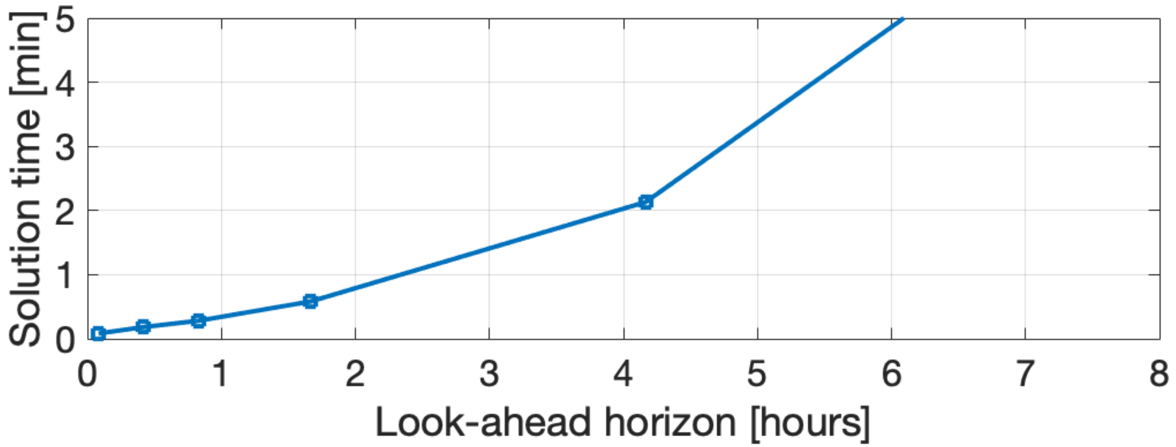
Theorem proved via KKT conditions

Xu, Bolun, et al. "A Lagrangian Policy for Optimal Energy Storage Control." *arXiv preprint arXiv:1901.09507* (2019).

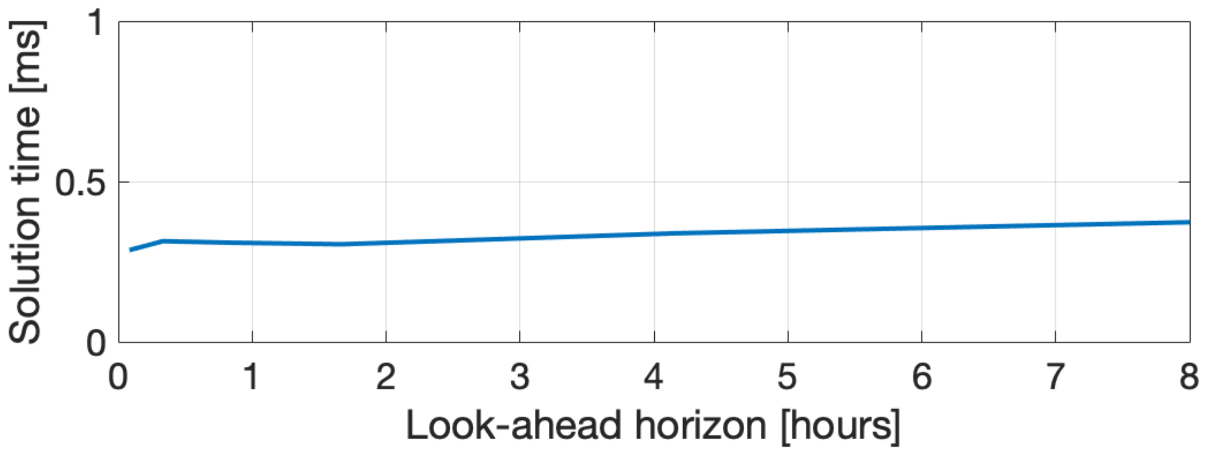
Constant space complexity, worst-case log-linear time complexity

Single Storage Computation Results - 5,000 segments / 5min

Gurobi – solution time in minutes



Proposed – solution time in milliseconds



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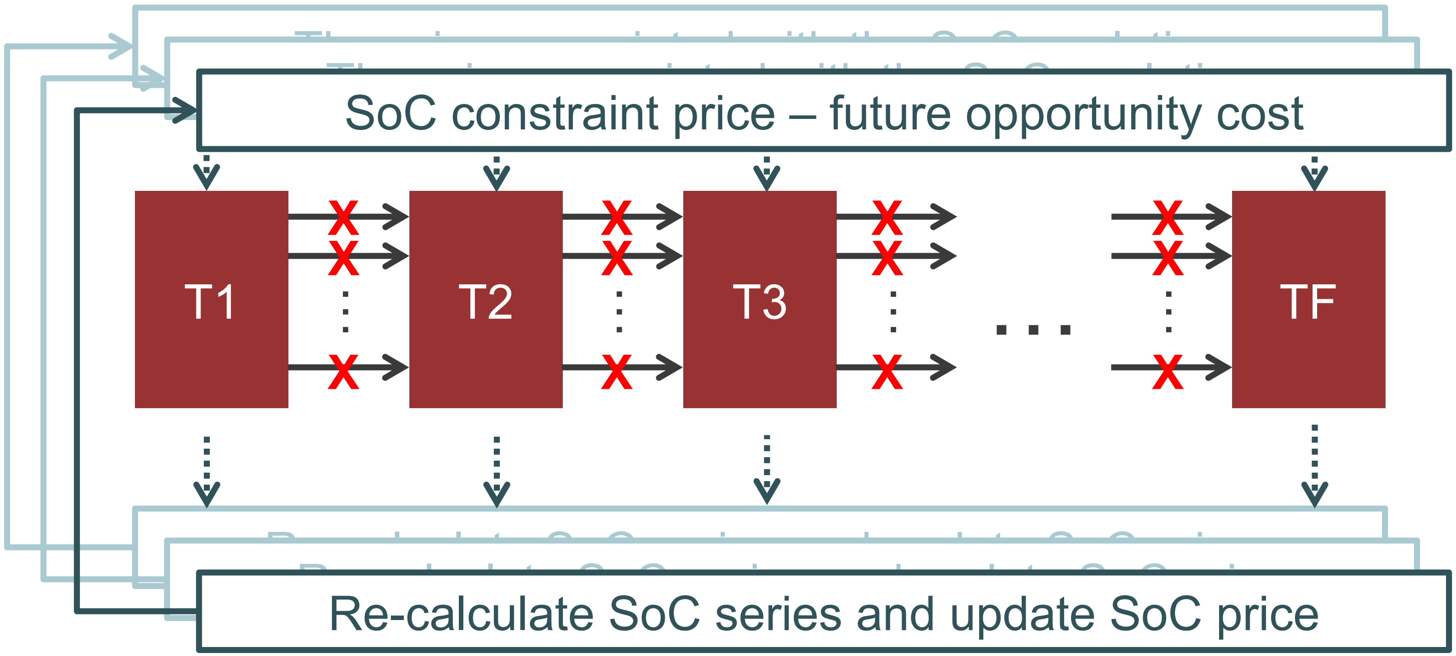
Optimization of Multiple Storage Devices



- Near optimal results for multiple storage devices (<0.1% error)
- Perfect scalability and parallelizable implementation
- Need additional solver for power flow computation
- Compatible with existing dispatch software

Computation Results – 24 hours with 5min resolution

	Gurobi	Proposed (series)	Proposed (parallel estimation)
No Network Constraints			
100 storage	1 second	1 second	5 ms
1,000 storage	1 minute	2 seconds	10 ms
10,000 storage	20 minutes	15 seconds	75 ms
300 Node Network (use Gurobi for OPF)			
300 storage	44 seconds	19 seconds	120 ms

- All errors less than 0.1%
- Additional solver required for OPF
- Each storage has different
  - Power rating, energy rating, efficiency
  - Initial SoC
  - Final SoC target
  - Degradation cost

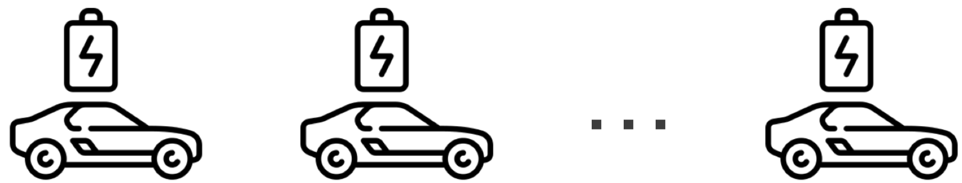
Plug-and-Play Aggregation for Local Services

Aggregator: Community control targets
EV charging / Peak shaving / Market aggregation

Charge and discharge price

Aggregation price broadcast

Price (dual variable) communication



Local agent algorithm update agent price

Advantages

- Broadcast communication
- Parallel agent algorithm / update
- Adaptive computation

Conclusion

- Fast storage optimization via dual (temporal) decomposition
- Single storage control
  - Solve all single storage problems in milliseconds
  - No commercial solver required
  - Optimal control under uncertainties (current work)
- System dispatch application
  - Dispatch storage with physical parameters
  - Storage pricing tool
- Plug-and-play aggregation
  - Compatible with other resource types