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Online Feedback Optimization of Energy Storage to Smooth Data Center Grid Impact

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Motivation

The growing electricity demand of **AI data centers** introduces significant voltage variability in power grids [1], affecting not only their own operation but also the experience of all users sharing the network. This work aims to utilize the widely adopted **battery** storage systems in the grid to help the grid. We develop an **online feedback optimization** (OFO) [2] approach that controls batteries to mitigate voltage issues induced by data center operations.

Research Questions

- How can we utilize batteries to provide effective long-term voltage regulations while respecting battery state of charge (SOC) and power constraints?
- Can we do so without perfect grid model and data center load predictions?

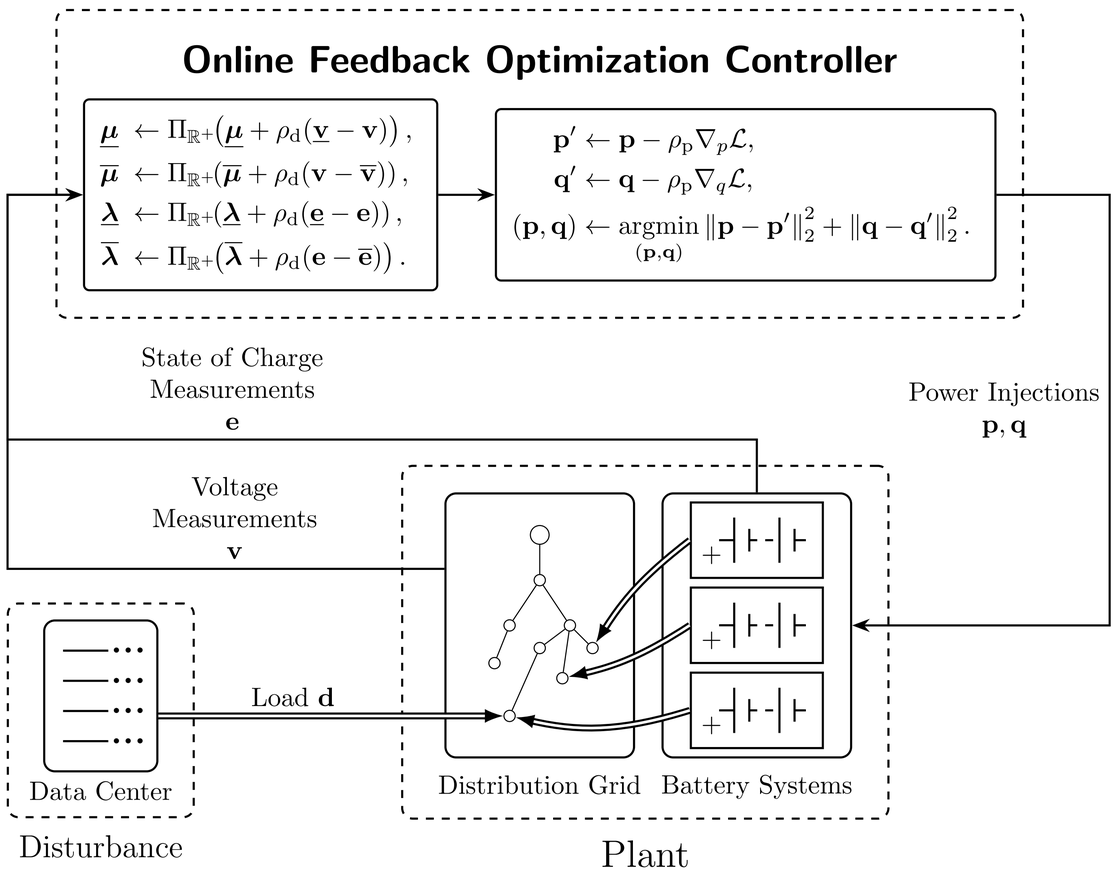
Methods–Online Feedback Optimization

The OFO problem follows a formulation similar to that of a conventional optimization problem, with the key distinction that the grid and battery energy models are replaced by voltage and SOC **measurements** $\mathbf{v}(\mathbf{p},\mathbf{q})$ and $\mathbf{e}(\mathbf{p},\mathbf{q})$.

$$
\begin{aligned}
\underset{\mathbf{p},\mathbf{q}}{\text{minimize}}\ & \tfrac{1}{2}\|\mathbf{v}(\mathbf{p},\mathbf{q})-\mathbf{v}_{\text{prev}}\|^2_{\mathbf{C}_{\text{vf}}}+\tfrac{1}{2}\|\mathbf{p}\|^2_{\mathbf{C}_{\text{p}}}+\tfrac{1}{2}\|\mathbf{q}\|^2_{\mathbf{C}_{\text{q}}} && \textit{penalties}\\
\text{subject to}\ & \underline{\mathbf{v}}\leqslant\mathbf{v}(\mathbf{p},\mathbf{q})\leqslant\overline{\mathbf{v}} \quad :\underline{\boldsymbol{\mu}},\overline{\boldsymbol{\mu}}, && \textit{voltage limits}\\
& \underline{\mathbf{e}}\leqslant\mathbf{e}(\mathbf{p},\mathbf{q})\leqslant\overline{\mathbf{e}} \quad :\underline{\boldsymbol{\lambda}},\overline{\boldsymbol{\lambda}}, && \textit{SOC physics}\\
& \underline{\mathbf{p}}_t\leqslant\mathbf{p}_t\leqslant\overline{\mathbf{p}}_t,\quad \forall t\in\mathcal{T}, && \textit{real power limits}\\
& \underline{h}(\mathbf{p}_t)\leqslant\mathbf{q}_t\leqslant\overline{h}(\mathbf{p}_t),\quad \forall t\in\mathcal{T}, && \textit{power factor limits}
\end{aligned}
$$

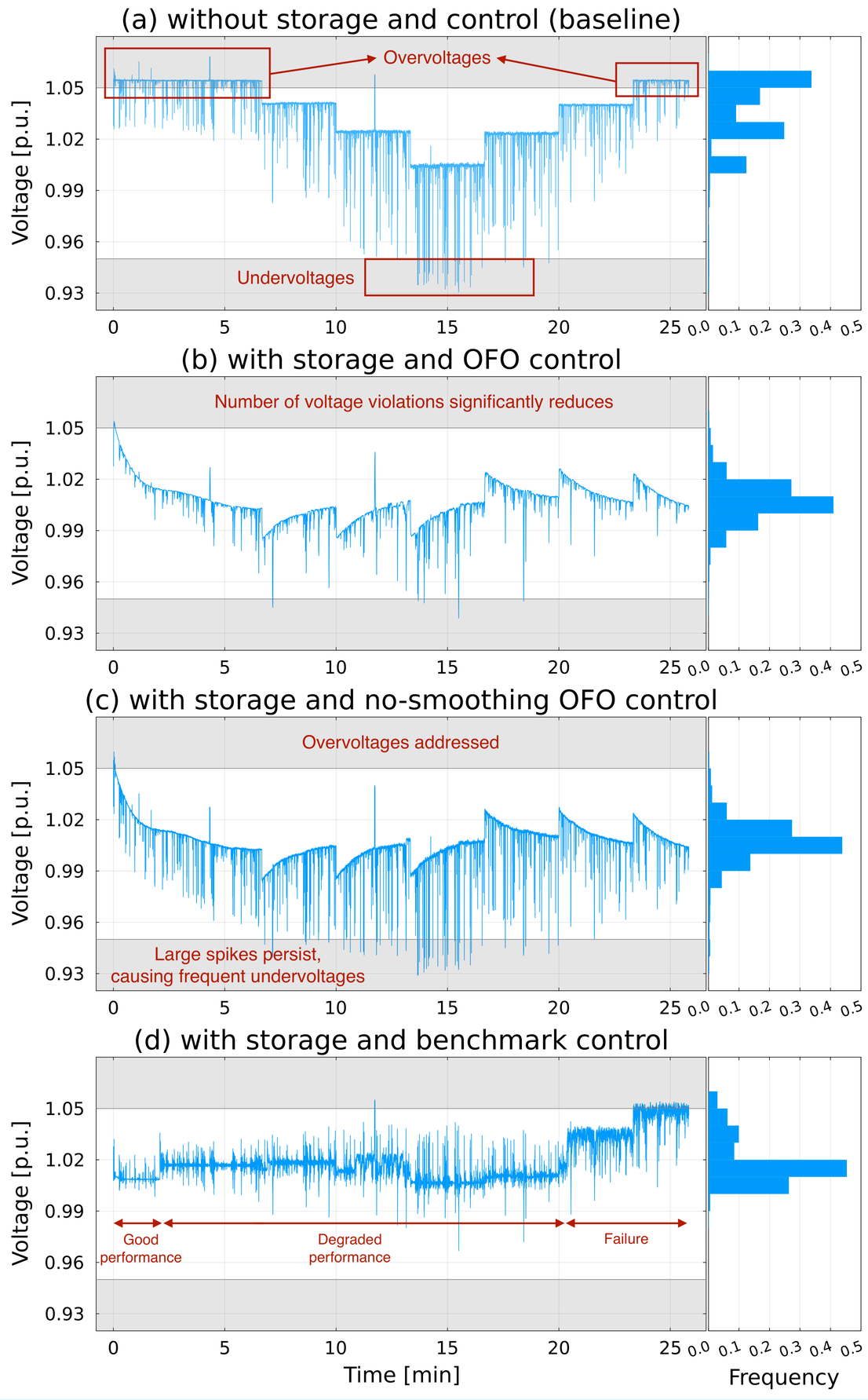
In this formulation, data center impacts are characterized by the voltage limit violations and intertemporal voltage fluctuations. At each time step t, the OFO controller updates itself by performing one dual-primal gradient step.

System diagram:



Results

The simulation results on IEEE 13-bus Test Feeder are shown in Figure .



Conclusion

While the local control approach pursues the objectives aggressively but hits quickly the energy limits and fails, the proposed OFO controller delivers consistent voltage regulation in the long term without the need for perfect model and prediction, facilitating the integration of data centers.

Acknowledgements

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References

[1] X. Chen, X. Wang, A. Colacelli, M. Lee, and L. Xie, "Electricity demand and grid impacts of ai data centers: Challenges and prospects," *arXiv preprint arXiv:2509.07218*, 2025.

[2] A. Hauswirth, Z. He, S. Bolognani, G. Hug, and F. Dörfler, "Optimization Algorithms as Robust Feedback Controllers," Jan. 2024.

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arXiv link to the full paper

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