Development of a Data Center Digital Twin

for Energy and Power Management System Design in Grid-Connected and Islanded Modes

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Electrical and Computer Engineering Department

Team Structure

Three Faculty Members

PI
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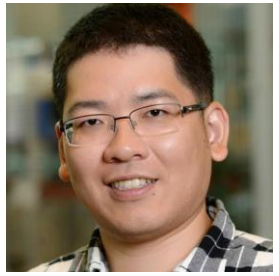
Digital-twin Development and Load Modeling



Co-PI
Wenyuan Tang
Energy Management and Forecasting

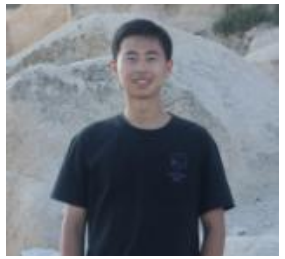
Co-PI:
Chau-Wai Wong
IT load Characteristics and Scheduling

Ph.D. student fellows

Zishuo Yang

Jongha Woo

Digital-Twin **Generator and Load Dynamic Model** Development



Yu Ma

Aaditya Pandey

Digital-Twin **Load Profile Model D**evelopment

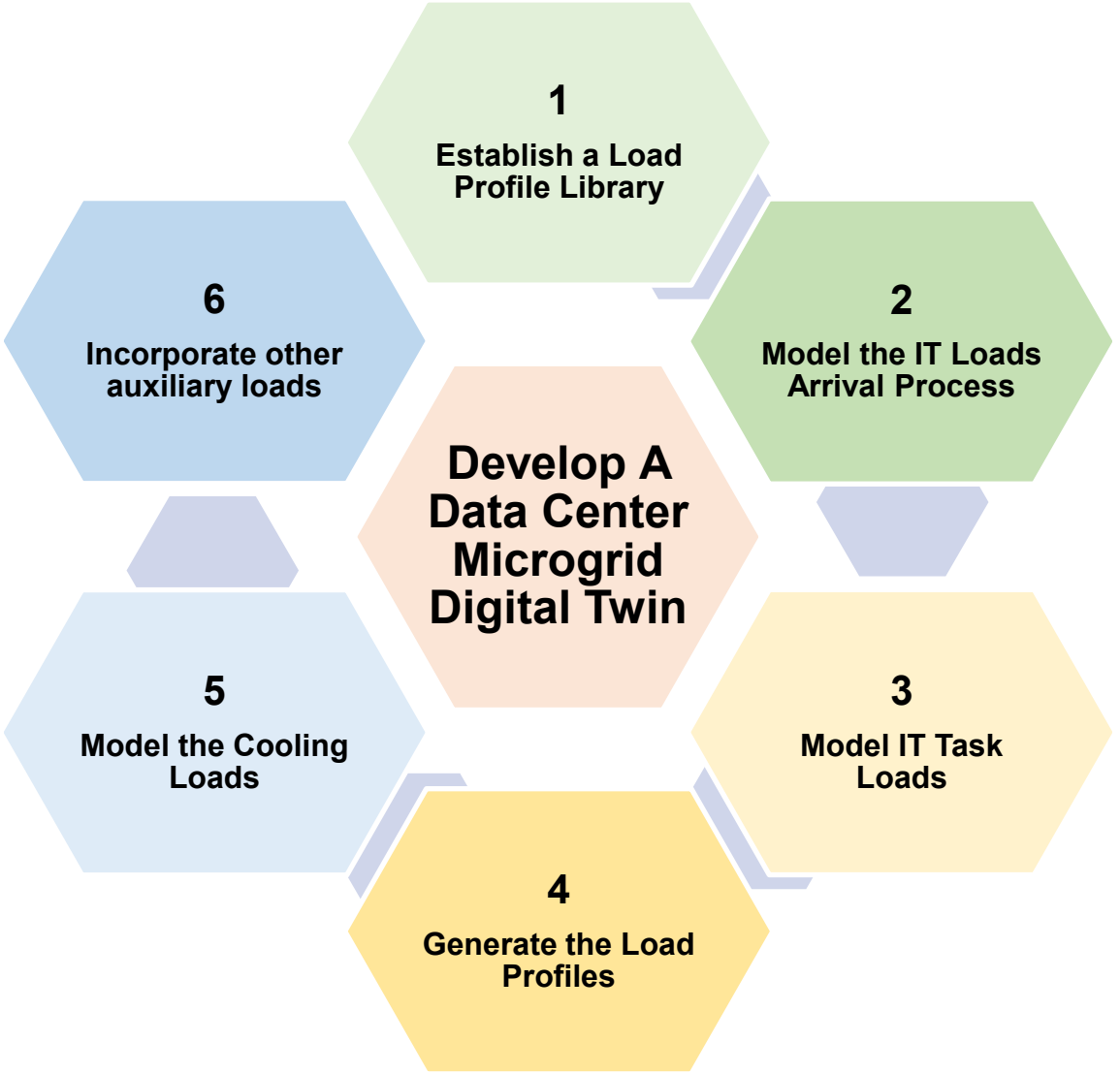
Undergraduate students

Anna Andriiko

Finn Sheng

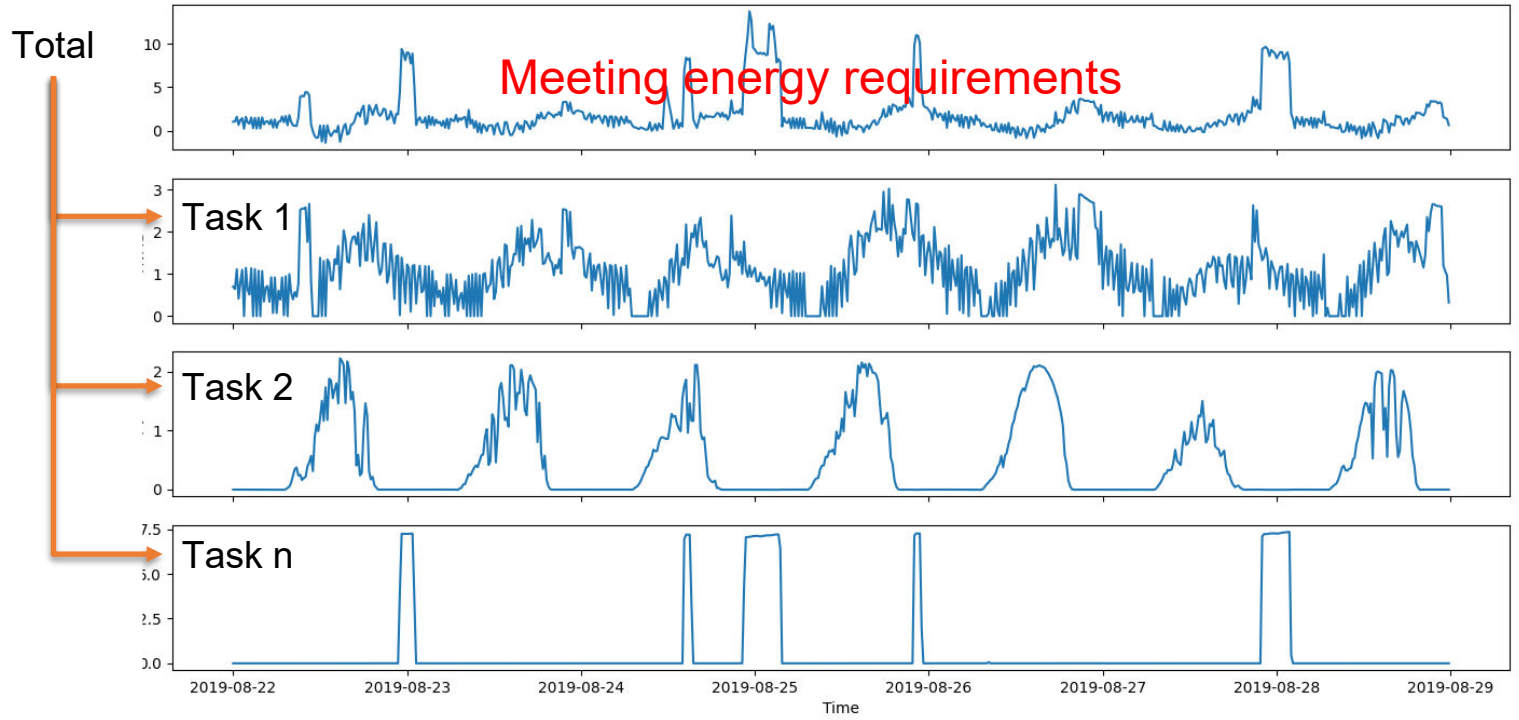
Methodology Overview

- Two approaches: **bottom-up** and **top-down** when simulation loads
- **2.5 MW** Microgrid
- **Aggregate** 2.5 MW to data-center level
- Generator Model (EMT):
  - Gas turbine/diesel generators
  - UPS and Battery Energy Storage Systems
  - Supper Capacitor
  - PVs
- Load Models:
  - ZIP loads
  - Motor loads
  - Power Electronics (EMT)



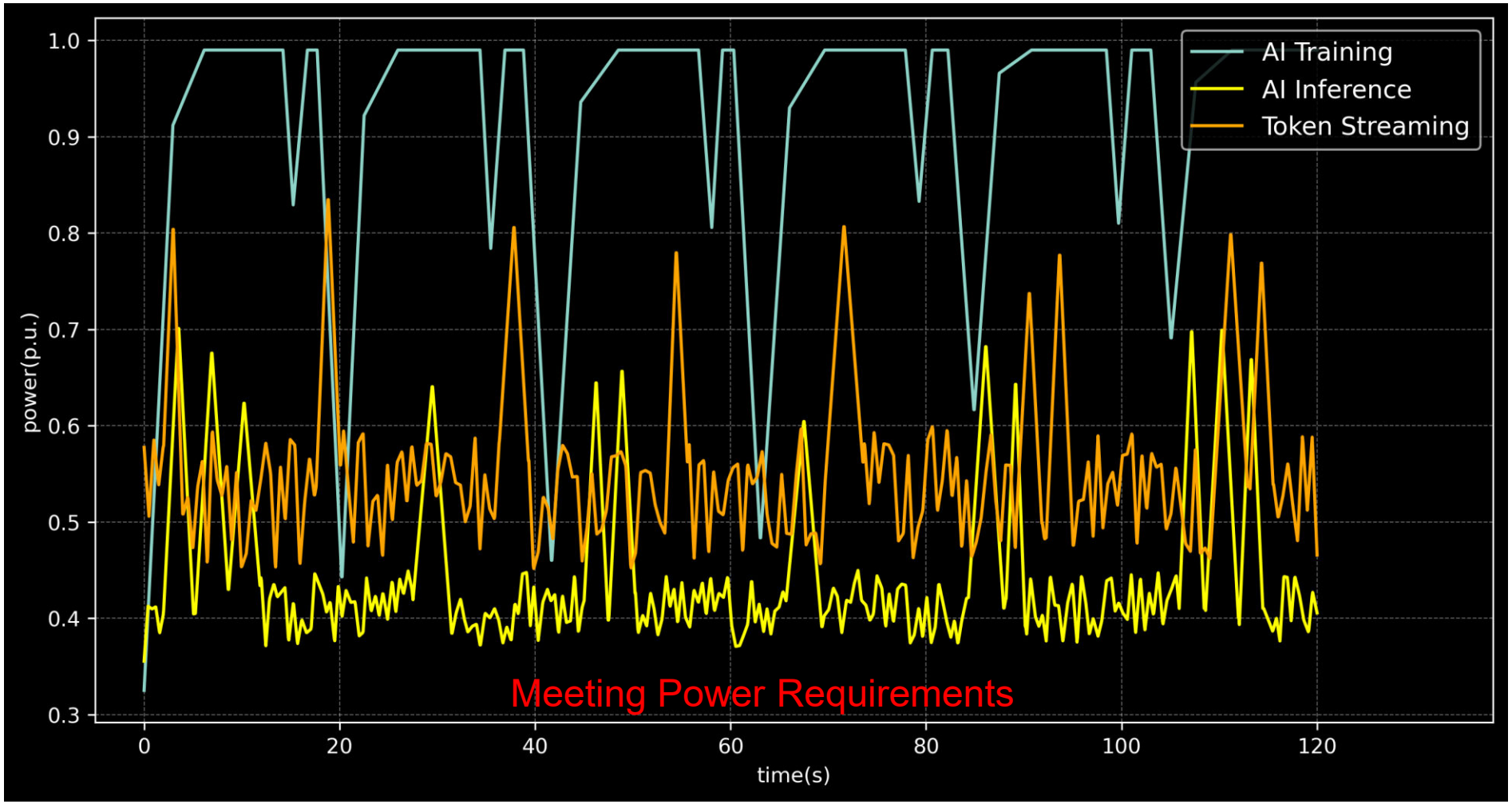
Top-down Approach: Load Disaggregation

- **Goal:** Decompose **IT load components** from the total consumption
- **Approach:** Modeling the different IT task combinations



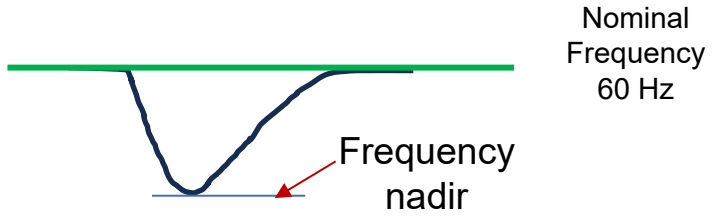
1. Kim, Hyeonjin, Kai Ye, Duehee Lee, et al. (2024). “A contextually supervised optimization-based HVAC load disaggregation methodology”. In: *IEEE Transactions on Smart Grid*.
2. Kim, Hyeonjin, Kai Ye, Han Pyo Lee, et al. (2023). “An ica-based hvac load disaggregation method using smart meter data”. In: *2023 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT)*. IEEE, pp. 1–5.
3. Ye, Kai et al. (2023). “A modified sequence-to-point hvac load disaggregation algorithm”. In: *2023 IEEE Power & Energy Society General Meeting (PESGM)*. IEEE, pp. 1–5.

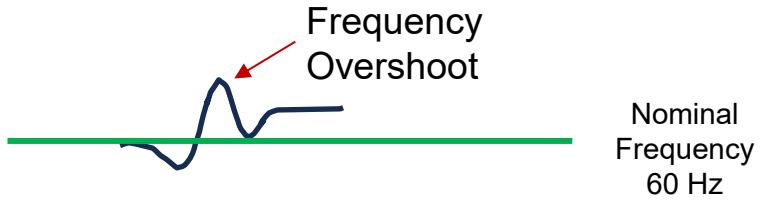
Bottom-up Approach

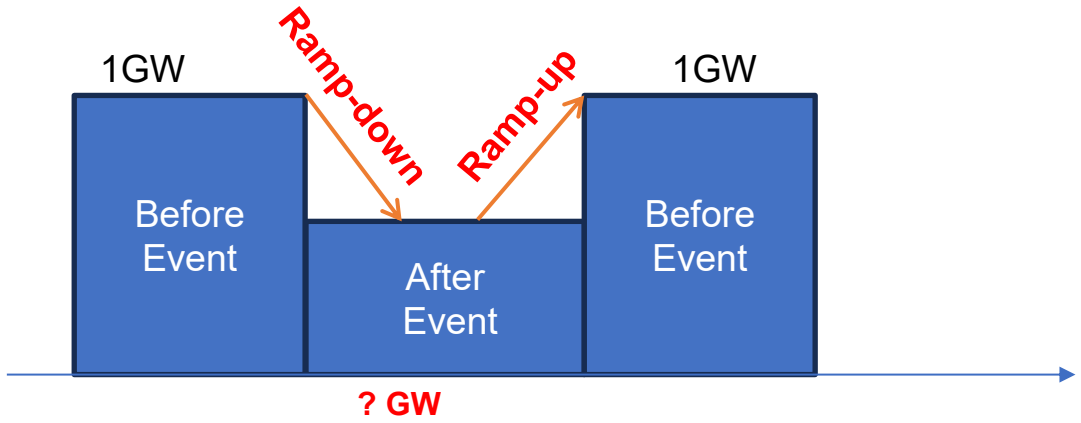


What load characteristics may be desired?

- The dynamic response of **Large Load Interconnection Study** may evaluate:
  - Frequency nadir / overshoot
  - Rate Of Change Of Frequency (ROCOF)
  - Voltage recovery
  - Generator responses
- We may need to specify
  - Maximum instantaneous load loss (MW)
  - Minimum post-fault retained load
  - Required staged shedding (e.g., blocks of 50–100 MW)
  - Load ramp-down / ramp-up rates

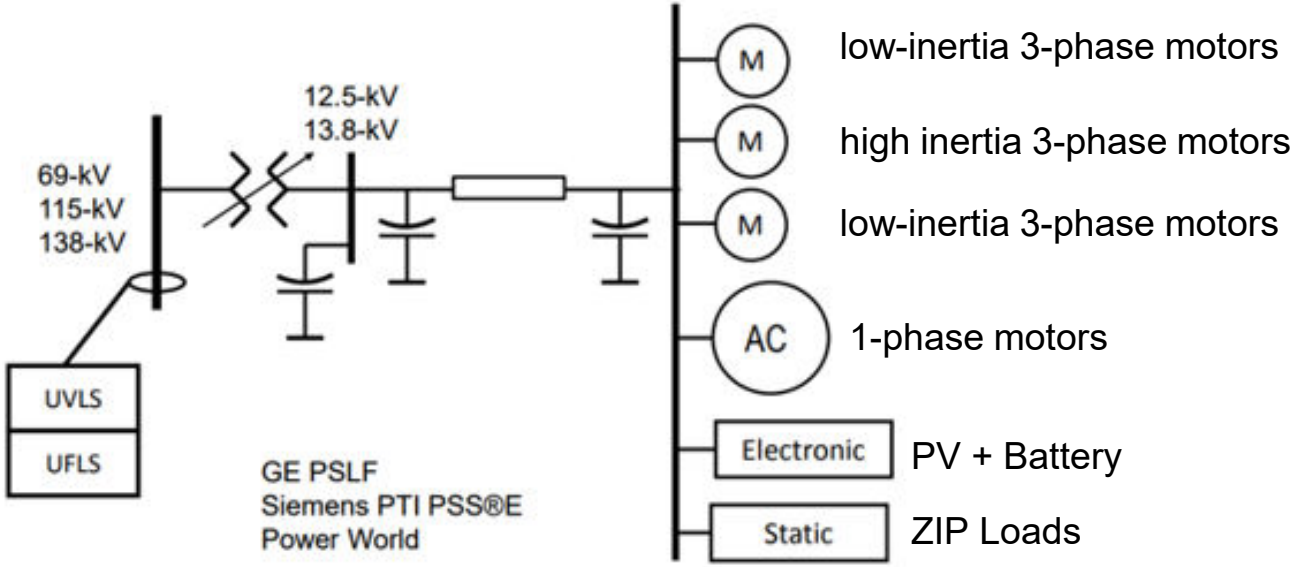






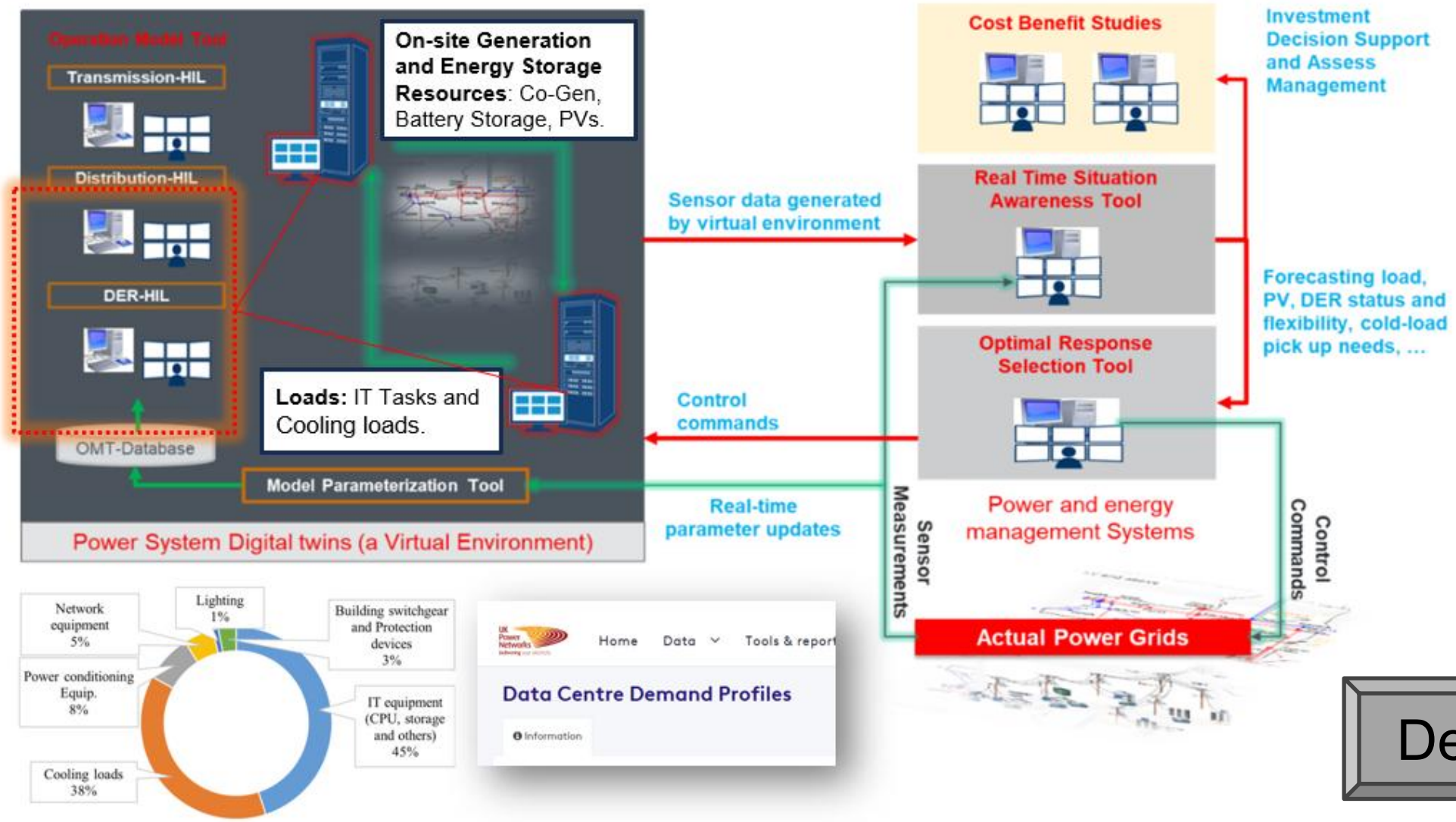
Can we use the composite load Models?

Category	Typical Large Loads	Main Characteristics	Typical Load Models
Data Centers (IDC)	AI Training, Cloud computing centers	High power density, near-constant load, high power quality	ZIP (P-dominant), Motors, Large synchronous Generators, UPS, Super Capacitors, Batteries



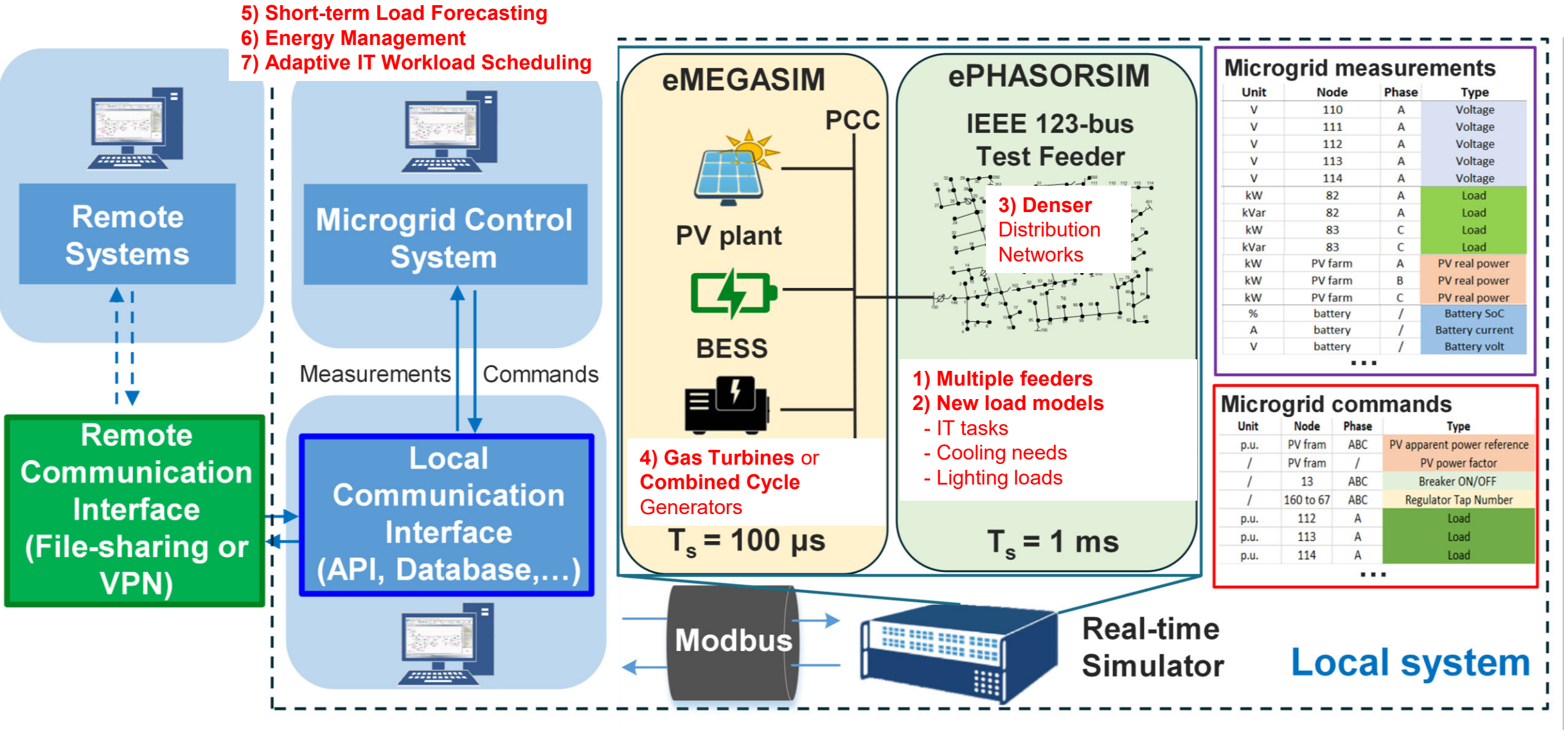
- The composite load model is an aggregated load representation.
- Primarily intended to capture the behavior of various motor-driven loads.
- It is not specifically designed for modeling data centers.

Data Flow for Running a Digital Twin

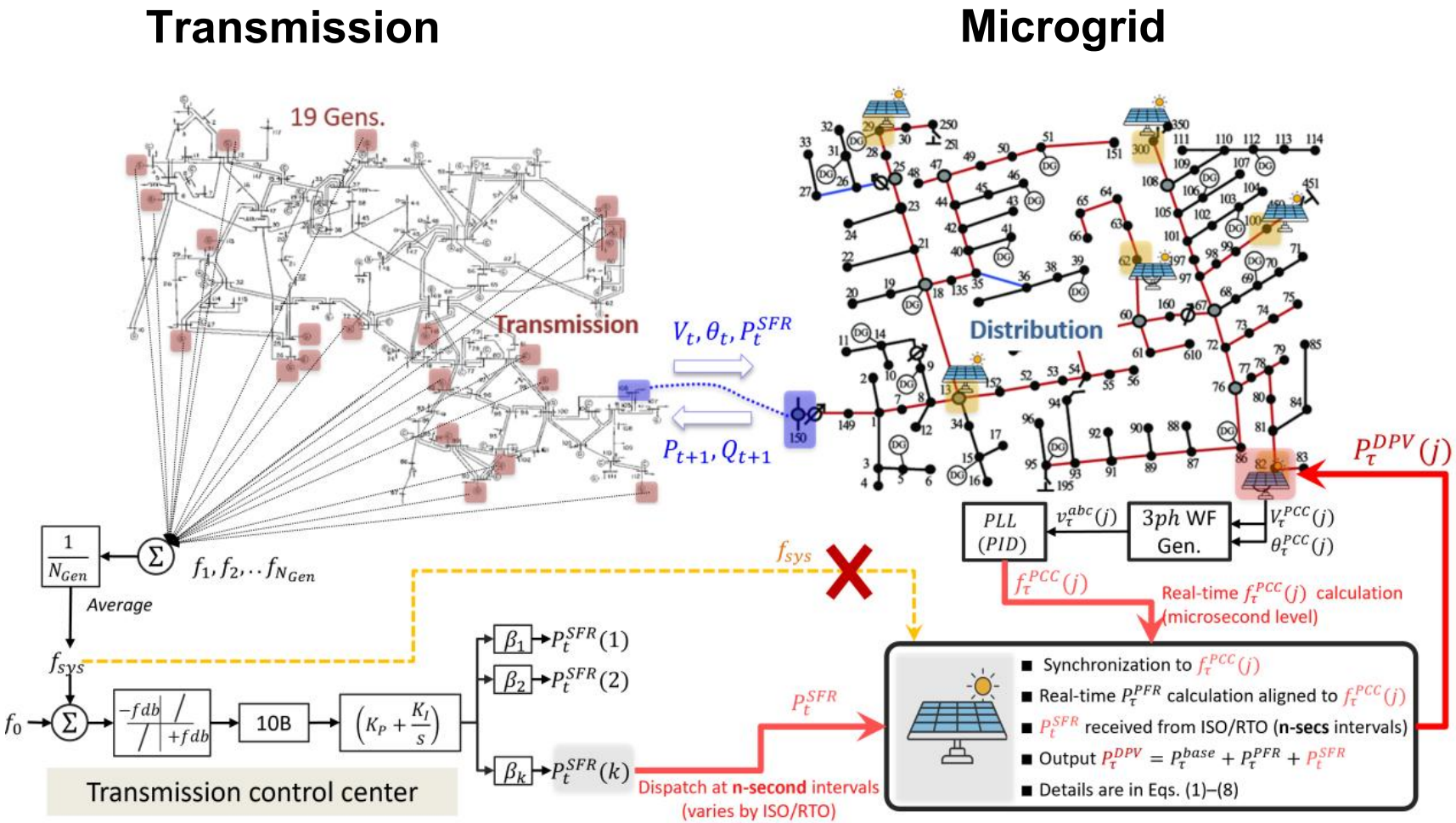


Demo

Data Center Digital Twin Layout



Co-simulation Approach



JH Woo, Q Xiao, Y Ma, Z Yang, VD Paduani, N Lu. Accurate Frequency Response Modeling in Integrated T&D Co-Simulation via RETA-Based Quadratic Extrapolation, Available at SSRN 5508821•papers.ssrn.com

Conclusions

- Data centers require **dedicated modeling approaches** due to their unique load composition and operating characteristics
- **Data-driven digital twin models** are essential to enable scalable, high-fidelity representation
- Modeling should **capture day-to-day operational dynamics**, rather than static or snapshot-based behavior
- **Modular model** designs are needed to flexibly address diverse data center architectures and use cases
- **Seamless integration** with large-scale power system models is critical for assessing grid interconnection and system-level impacts