

Development of a Data Center Digital Twin

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

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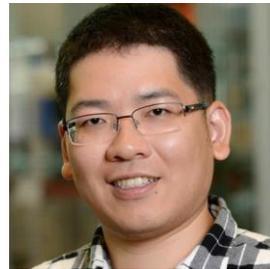
Electrical and Computer Engineering Department

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



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**Yu
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**Aaditya
Pandey**

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

Digital-Twin **Load Profile
Model Development**

Undergraduate students



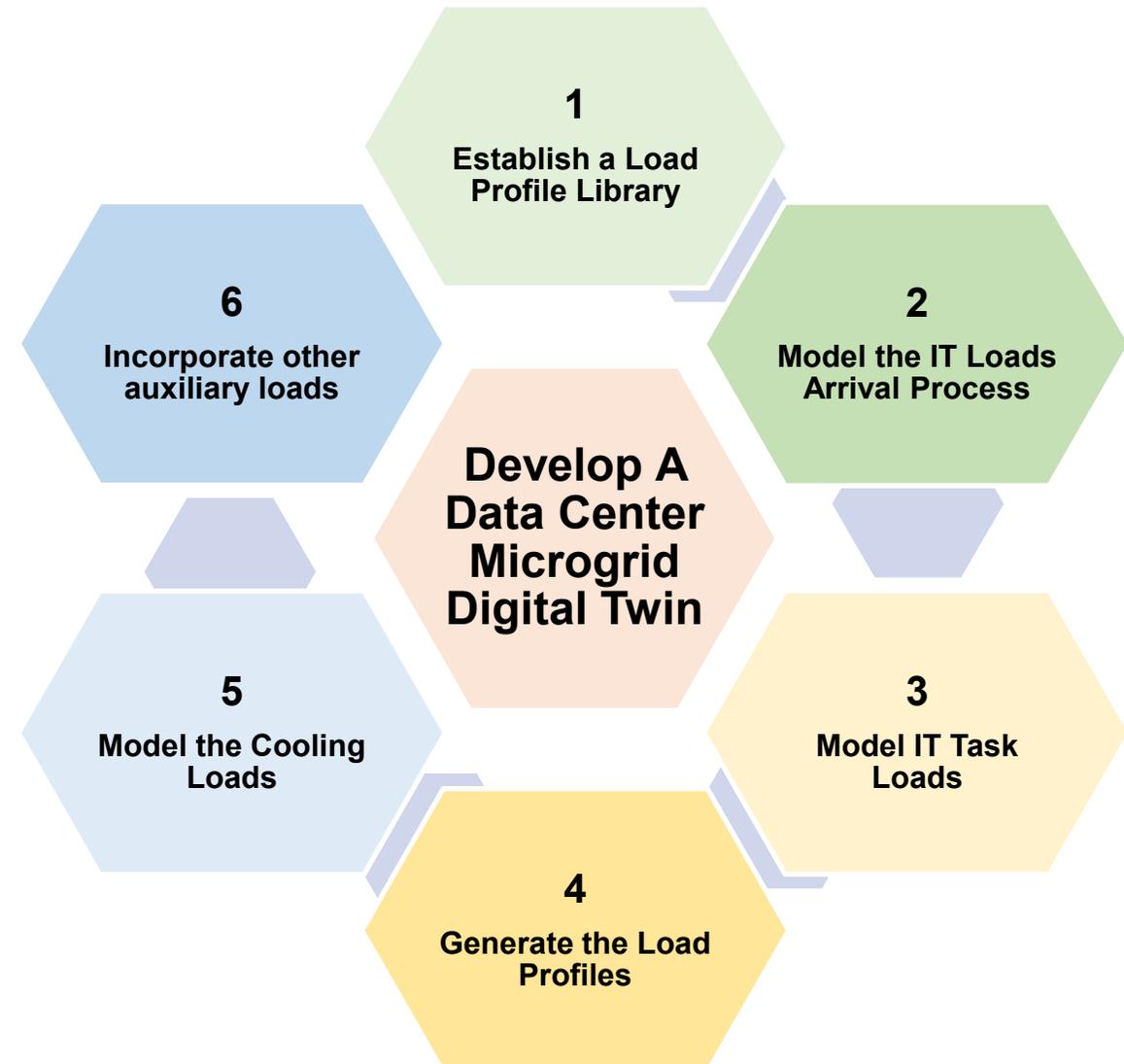
**Anna
Andriiko**



**Finn
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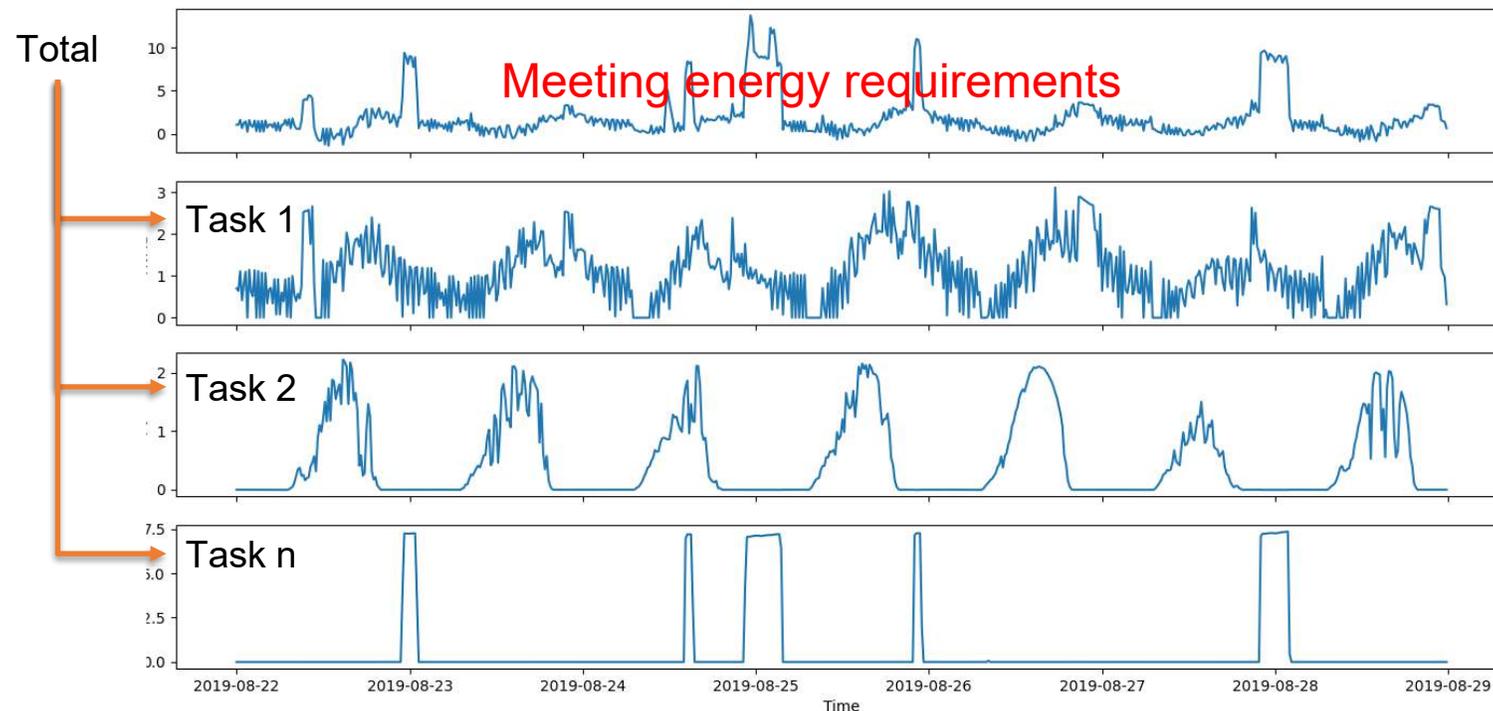
Methodology Overview

- 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)



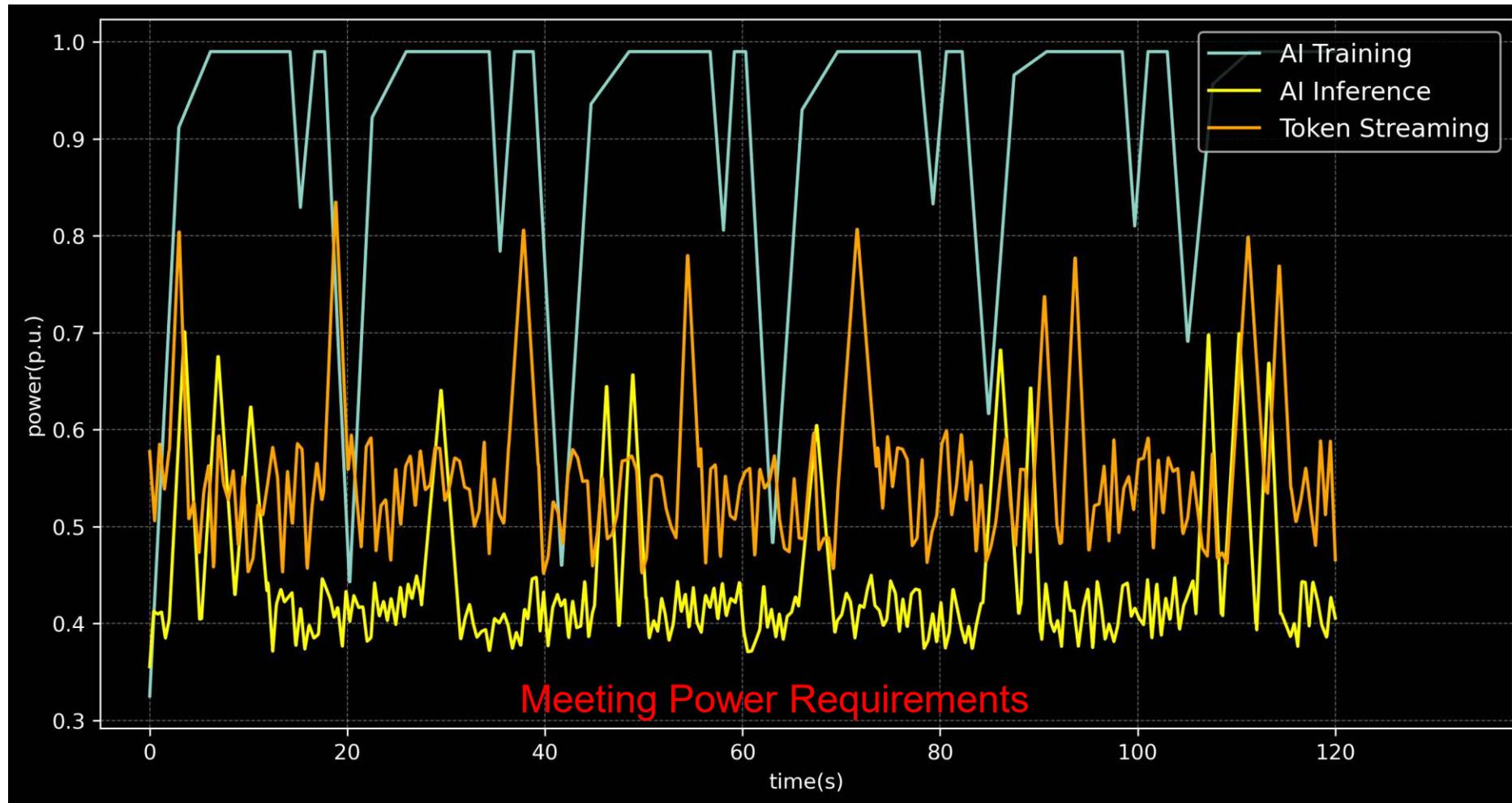
Top-down Approach: Load Disaggregation

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



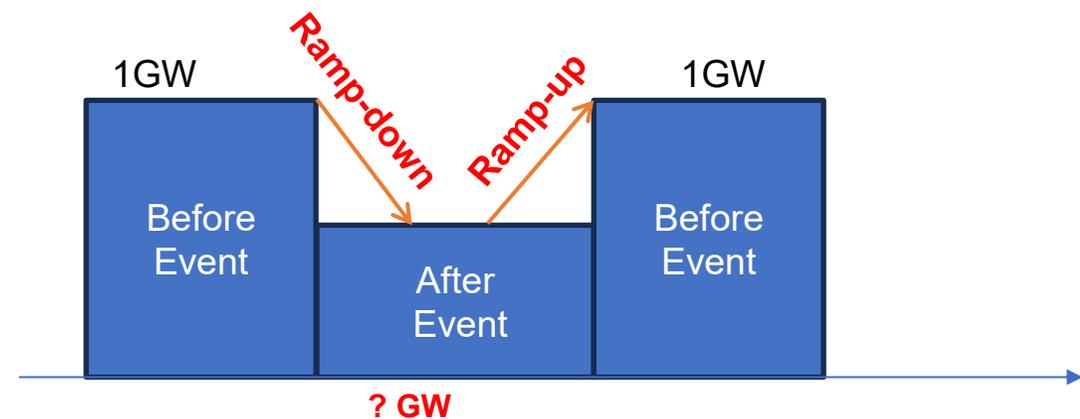
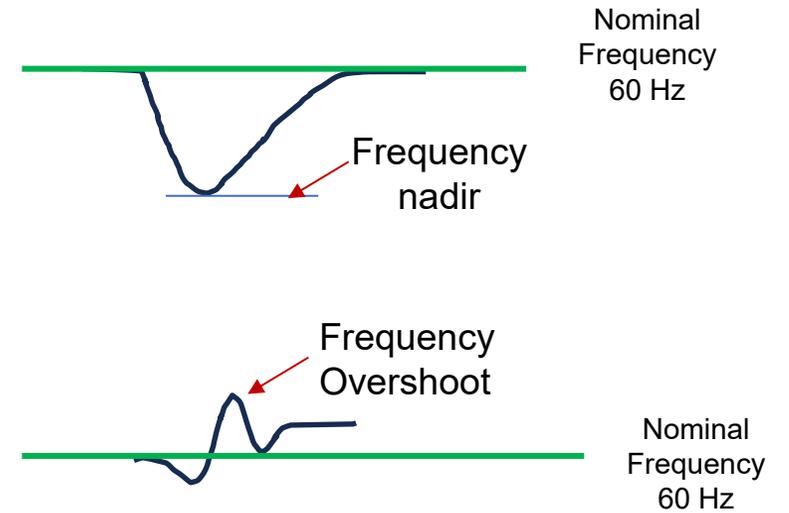
1. Kim, Hyeonjin, Kai Ye, Duehee Lee, et al. (2024). "A contextually supervised optimization-based HVAC load disaggregation methodology". In: *IEEE Transactions on Smart Grid*.
2. Kim, Hyeonjin, Kai Ye, Han Pyo Lee, et al. (2023). "An ica-based hvac load disaggregation method using smart meter data". 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



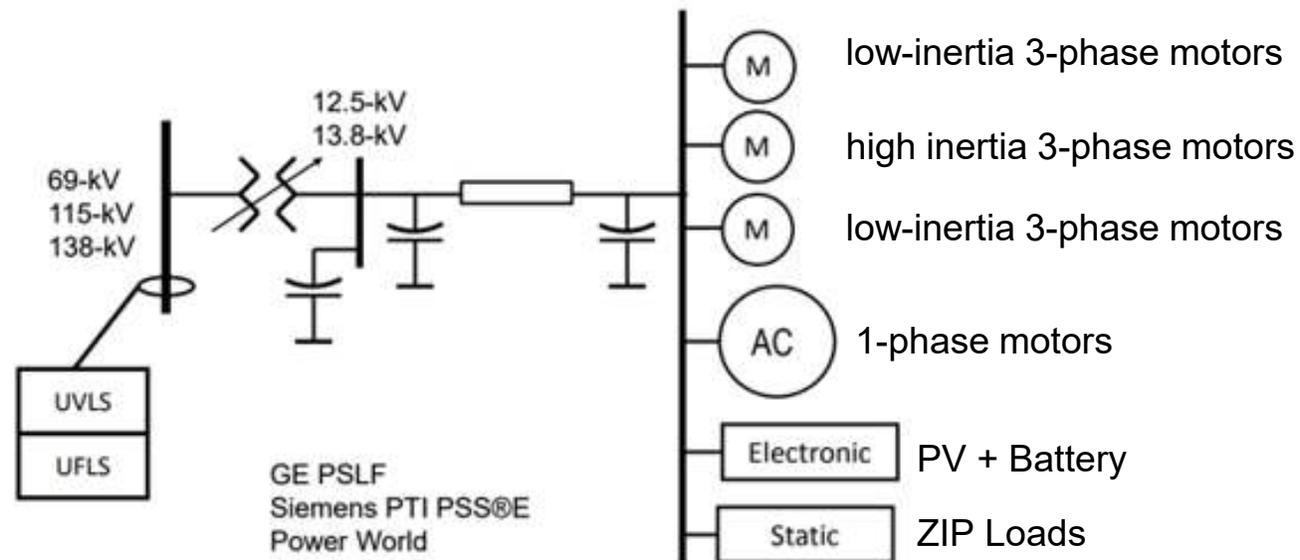
What load characteristics may be desired?

- 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



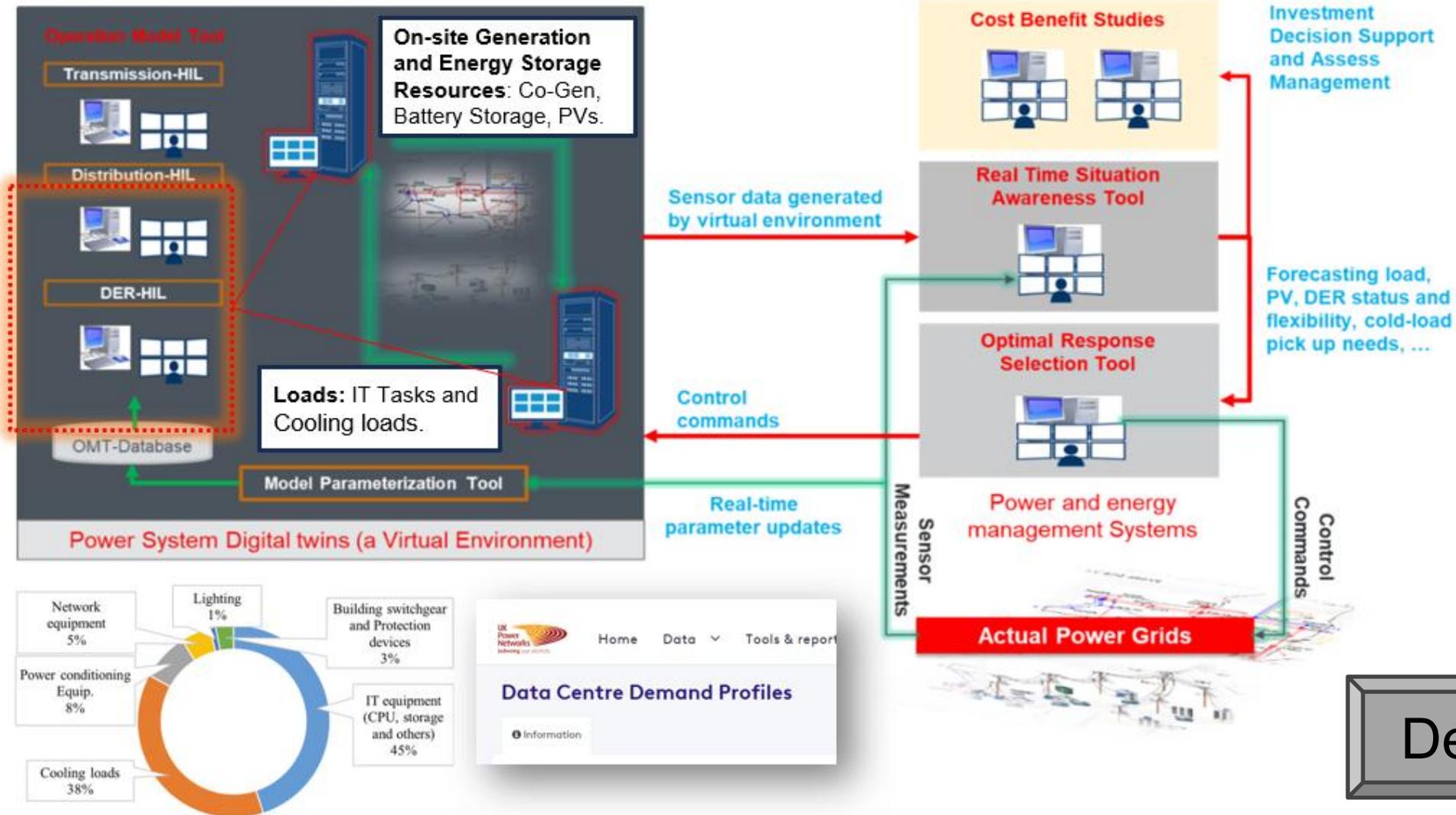
Can we use the composite load Models?

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.

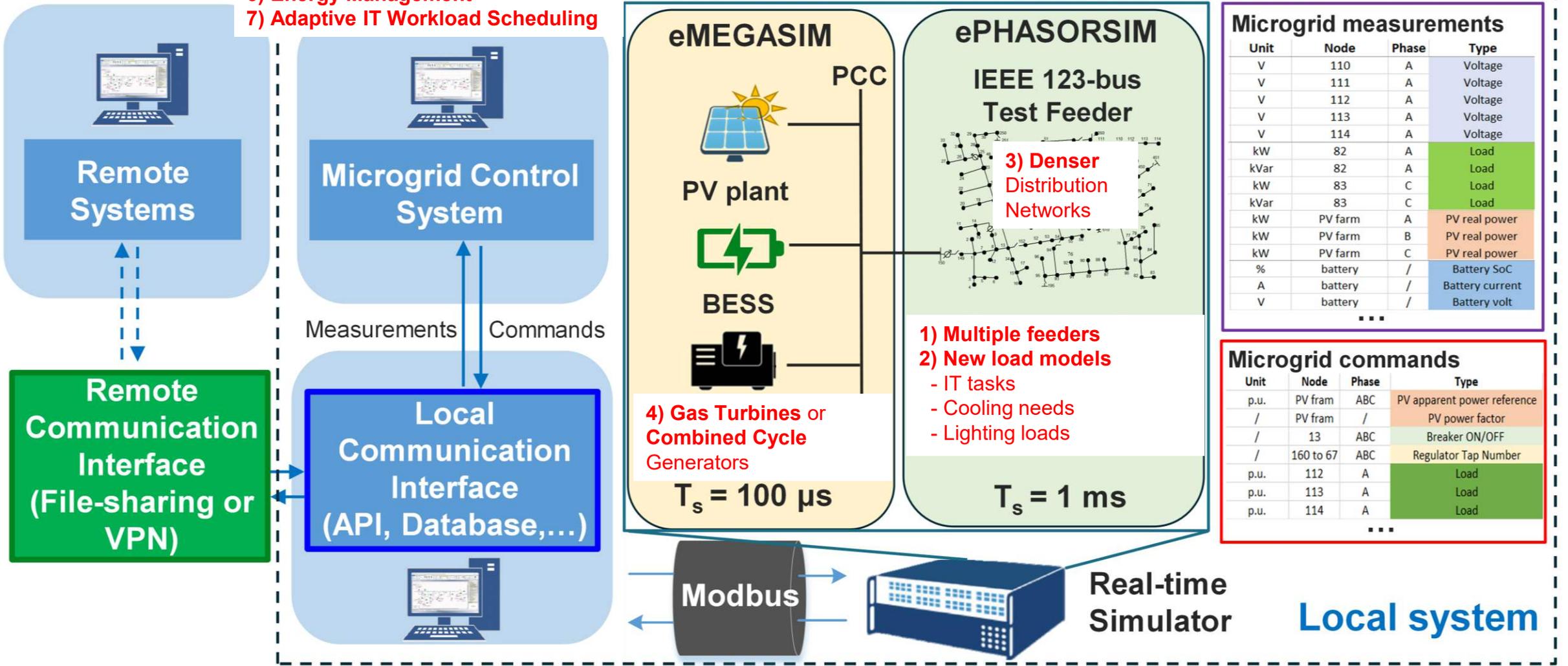
Data Flow for Running a Digital Twin



Demo

Data Center Digital Twin Layout

- 5) Short-term Load Forecasting
- 6) Energy Management
- 7) Adaptive IT Workload Scheduling



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