Intelligent Digital Twin for a College-town Electric Power Network

Keynote Speech

CSER Conference, George Mason University, Arlington, VA

Professor Saifur Rahman, IEEE Life Fellow
Director, Virginia Tech Advanced Research Inst.
2023 IEEE President
07 April 2026


PPT slides are available at
www.srahman.org

Saifur Rahman

2023 IEEE President and CEO

HOME ACHIEVEMENTS RESEARCH AND PUBLICATIONS PRESENTATIONS MEDIA BLOG

www.srahman.org

Date	Recent and Upcoming Presentations and Webinars	Webinar/Presentation Slides

7 April 2026
USA

An Intelligent Digital Twin Simulator for a Collage-town Power System
Keynote Speech, CSER Conference, George Mason University, Arlington, VA

Blacksburg is a college-town whose electric network is operated by Virginia Tech Electric Service (VTES). The system supplies power to the Virginia Tech campus and a large portion of the surrounding town. VTES receives bulk power from Appalachian Power (AEP) at 66 kV. The voltage is stepped down at four substations to 11 kV for primary distribution. These feeders serve campus facilities, residential streets, commercial customers, and small industrial loads. This layered structure represents a typical yet highly dynamic distribution system, where load behavior, increasing rooftop solar PV, distributed energy resources, and operational limits constantly influence each other. Renewable energy sources, battery energy storage systems, and electrified loads such as EV charging introduce variability, bidirectional power flows, and tighter voltage margins. This project is geared to developing tools that reflect the live-state of the system and anticipate what may happen next. An Intelligent Digital Twin Simulator (IDTS) offers this capability which is a continuously synchronized virtual replica of the physical network. It evaluates "what-if" scenarios under realistic constraints. It acts as a decision support engine rather than a visualization tool.


CSER 2026
conference on systems engineering research
6-9 April 2026
ARLINGTON, VA
Registration Now Open
Intelligent Digital Twin-enabled
Systems Engineering
for 21st Century
Sociotechnical Systems

What is a Digital Twin

A digital twin is a dynamic, virtual replica of a physical object, system, or process, updated in real time using sensor data and IoT technology. By mirroring its physical counterpart, a digital twin enables simulation, performance monitoring, and predictive analysis to optimize operations and predict failures before they occur.

Virtual Replica of a Building: A Digital Twin

Helps to study how a building's electricity consumption will vary depending on various environmental constraints placed on the building

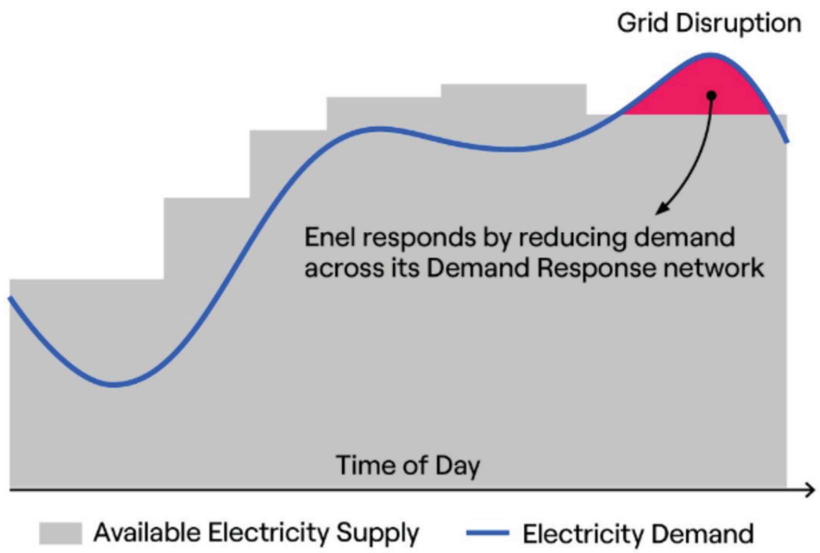
Why is this Important

- Electricity supply capacity is stressed during extreme weather conditions
- Household load increases sharply when EVs, air conditioners run together
- Time-of-use rates make electricity more expensive in high-demand periods

Peak Hour Demand Reduction for Cost Savings

Managing the Electric Power Delivery During Stressed Conditions

- Level of customer response needed to achieve a certain objective
- Study customer response to various control actions
- Diurnal variations in customer response
- Cost of incentives



Would You Rather Pay a Penalty or Earn Money

Demand Response is an electric utility program where electricity consumers—households or businesses—are <u>incentivized or paid to voluntarily reduce or shift their energy usage</u> during peak times or when the power grid is under stress. Alternative is paying higher electricity rates.

Impact of Demand Response

Controlling electricity supply impacts the building's comfort level

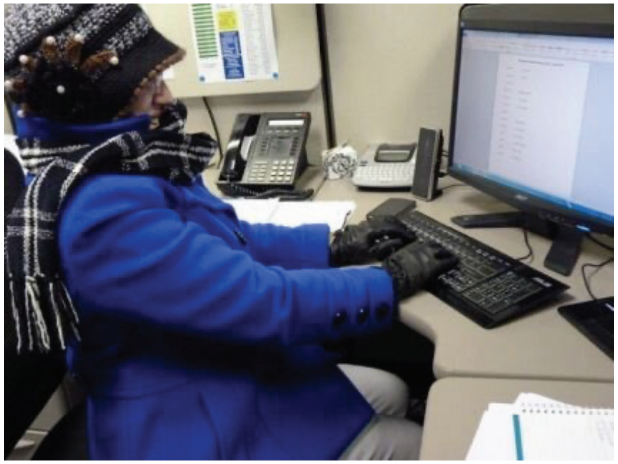
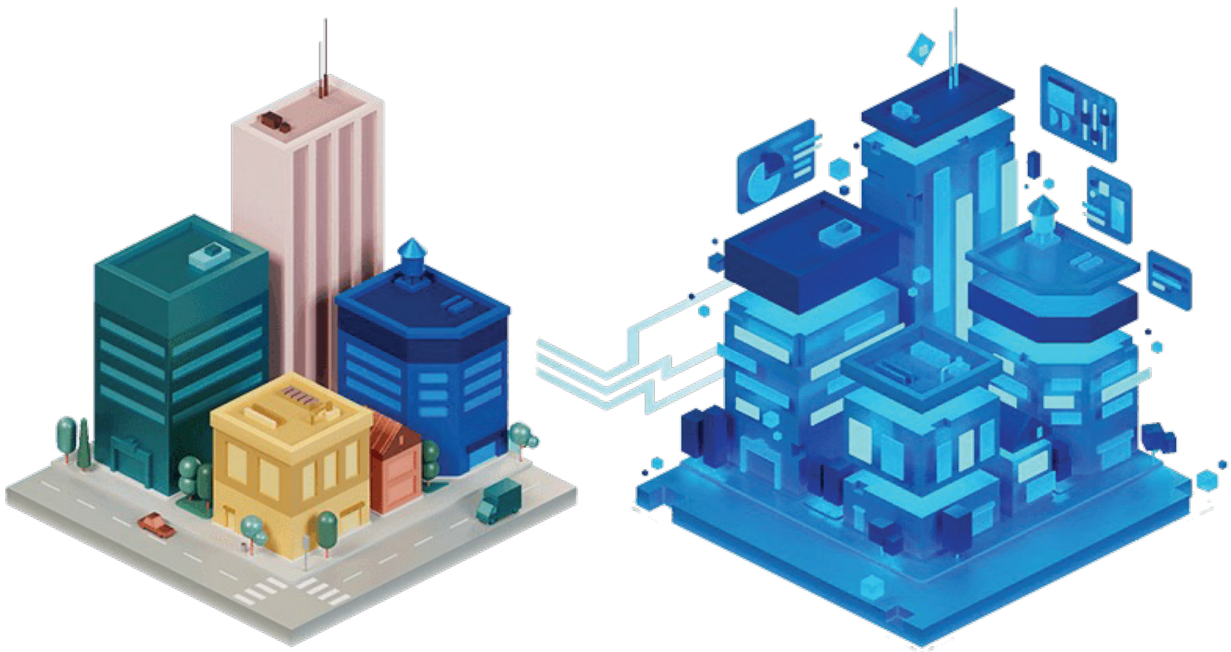


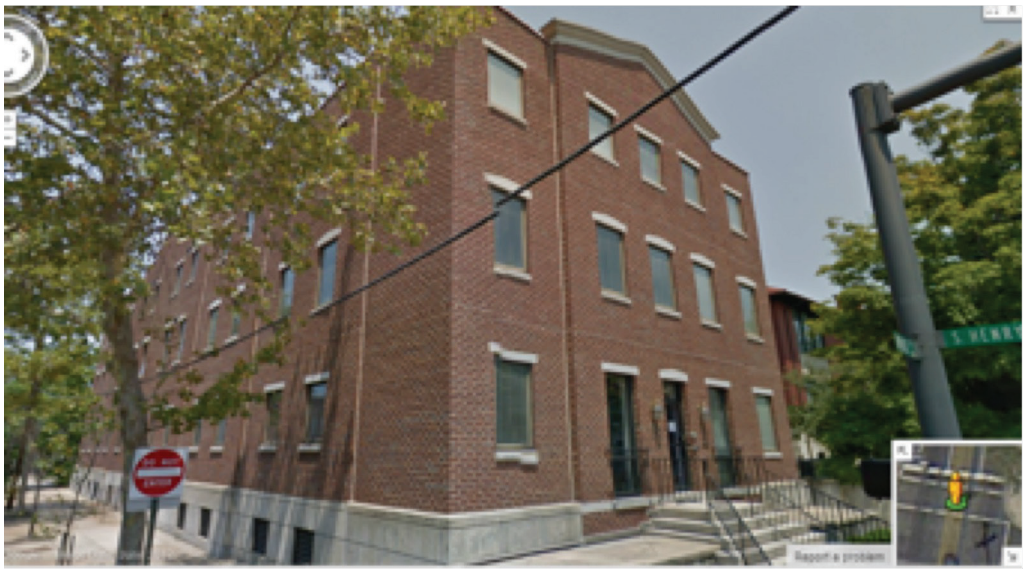
Figure out what you can tolerate before it becomes non-tolerable

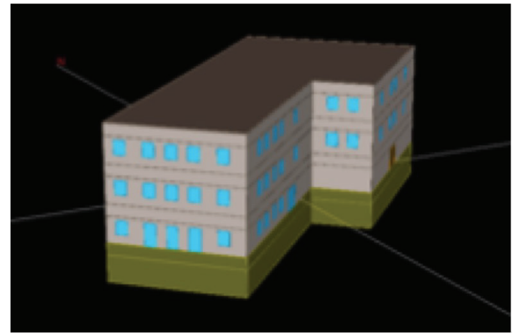
Let the Building-twin be the Guinea-pig not the Real Building

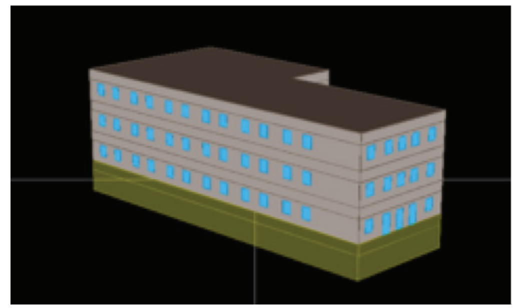


Digital Twins of Classroom & Retail Office Buildings to Study the Impacts of Demand Response

Building 1 – Classroom



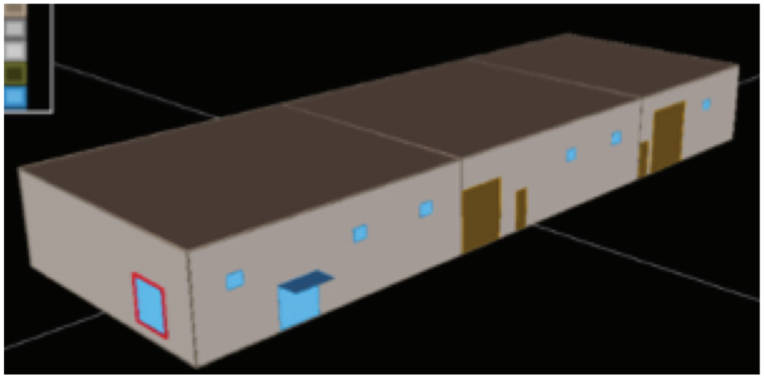




Area: 25,000 sqft

Monthly consumption: 14-27MWh

Building 2 – Retail Office



Area: 8,500 sqft

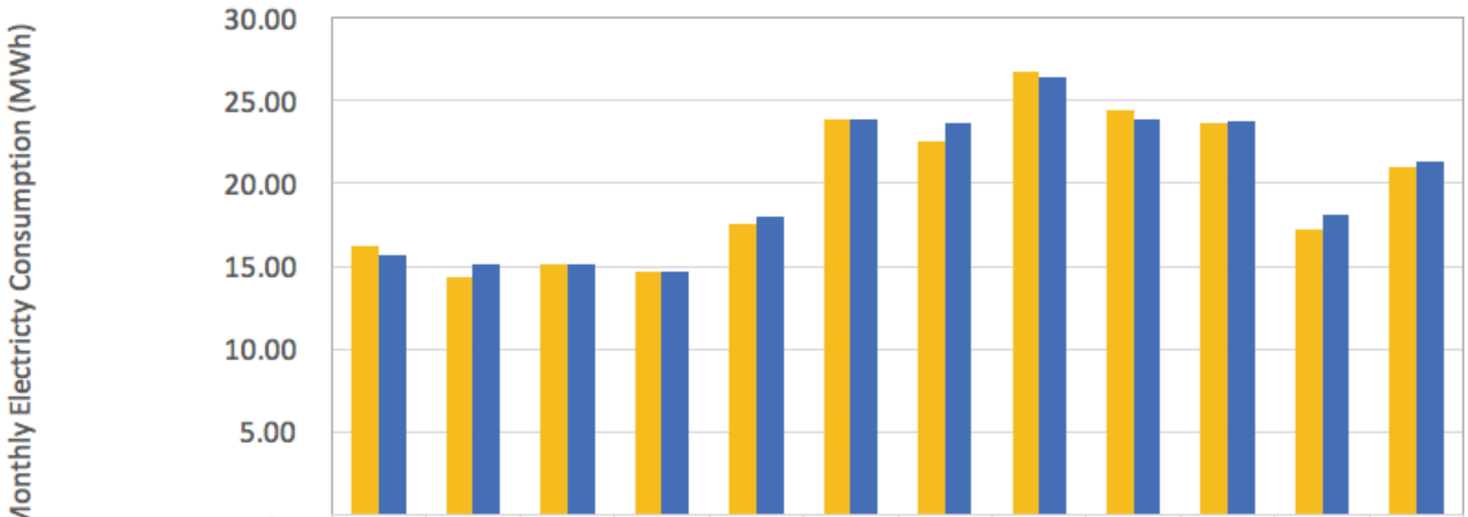
Monthly consumption: 4-10MWh

Building Data Needed

- Building area
- Total area
- Building footprint (e.g., square, rectangle, L-shape)
- Building operation
- Door orientation
- Skylight area
- Distribution of windows
- Door type
- 30-minute smart meter data in kWh
- Building type (e.g., office, retail, restaurant, etc.)

Building 1 – Model Validation

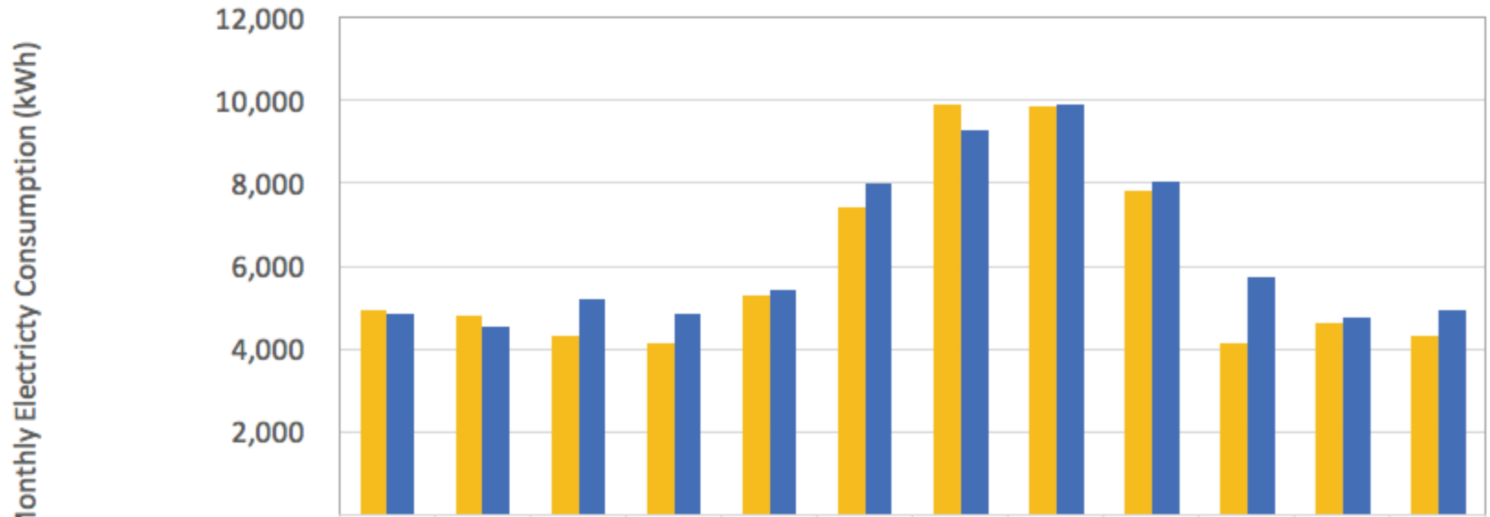
Monthly metered data vs simulation data



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Building MWh (actual)	16.24	14.32	15.10	14.64	17.60	23.84	22.56	26.72	24.48	23.68	17.20	21.04
Building MWh (simulated)	15.65	15.15	15.10	14.70	17.98	23.93	23.66	26.42	23.84	23.79	18.16	21.32

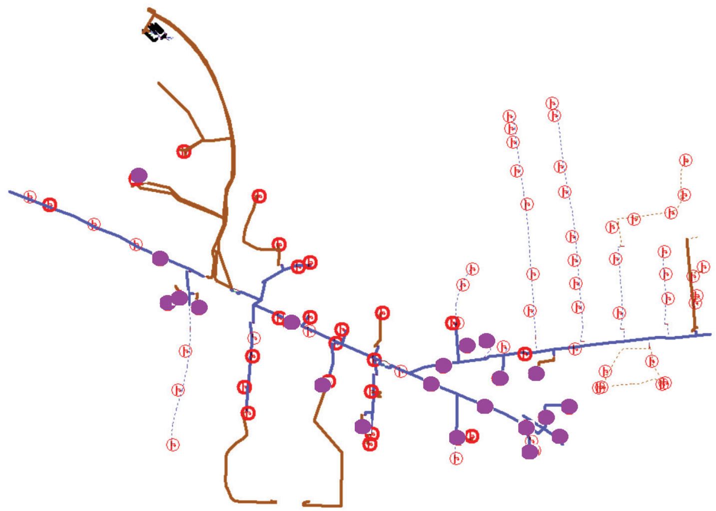
Building 2 – Model Validation

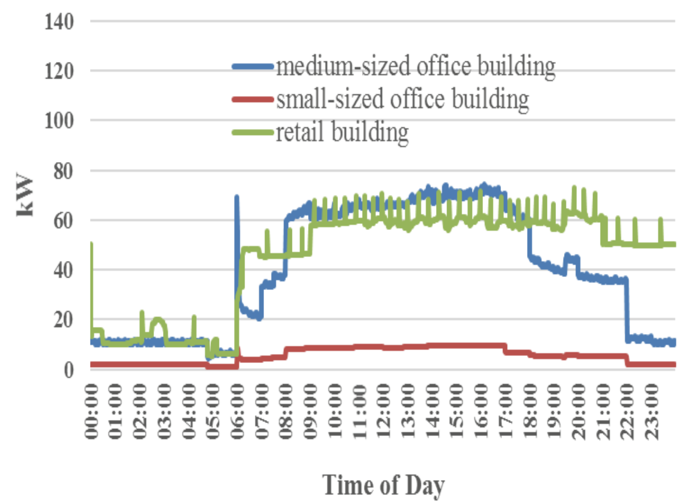
Monthly metered data vs simulation data



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Building kWh (actual)	4,960	4,800	4,320	4,160	5,280	7,440	9,920	9,840	7,840	4,160	4,640	4,320
Building kWh (simulated)	4,870	4,540	5,224	4,871	5,418	8,018	9,290	9,888	8,061	5,724	4,765	4,950

Demand Response: From one Buildings to Many



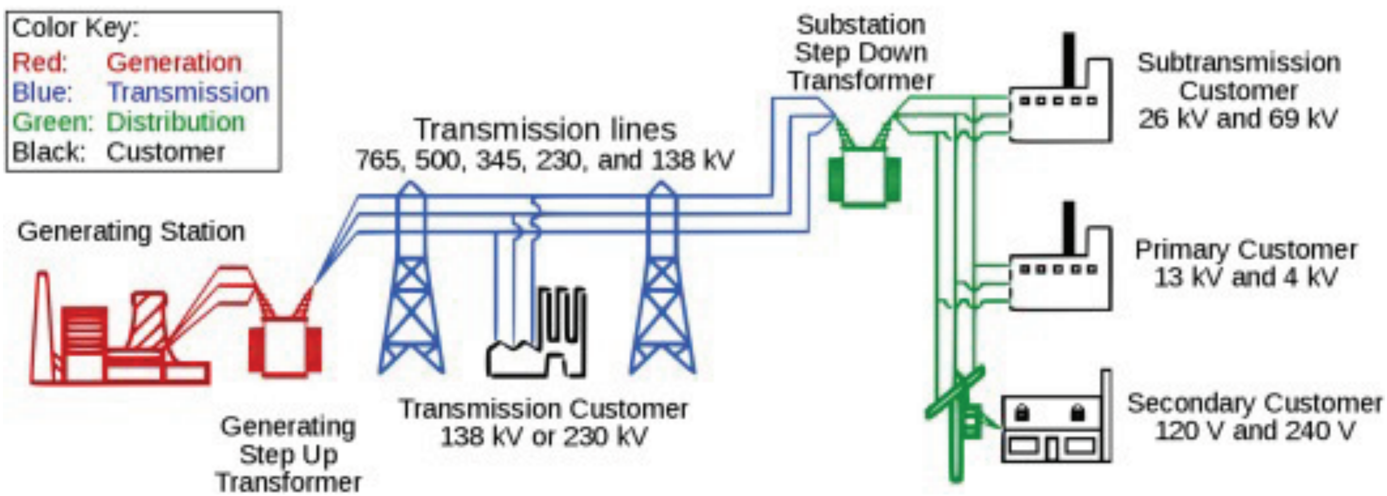


Power consumption profiles for demand responsive commercial buildings

Source: Fakeha Sehar, 2017

Power Distribution Network

- Substations step down voltage to distribution level
- Feeders carry power to neighborhoods and campus
- Supplies homes, buildings, and small industries
- Today, energy sources are also connected at the distribution level (DER).



Greater Complexity: Virginia Tech Electric Service

- Highly variable demand (class hours, nights, weekends)
- Event-driven peaks (football games, concerts)
- Mixed load types (academic, residential, commercial)
- Growing DERs (solar, EV charging, storage)
- Depends a lot on academic calendar.

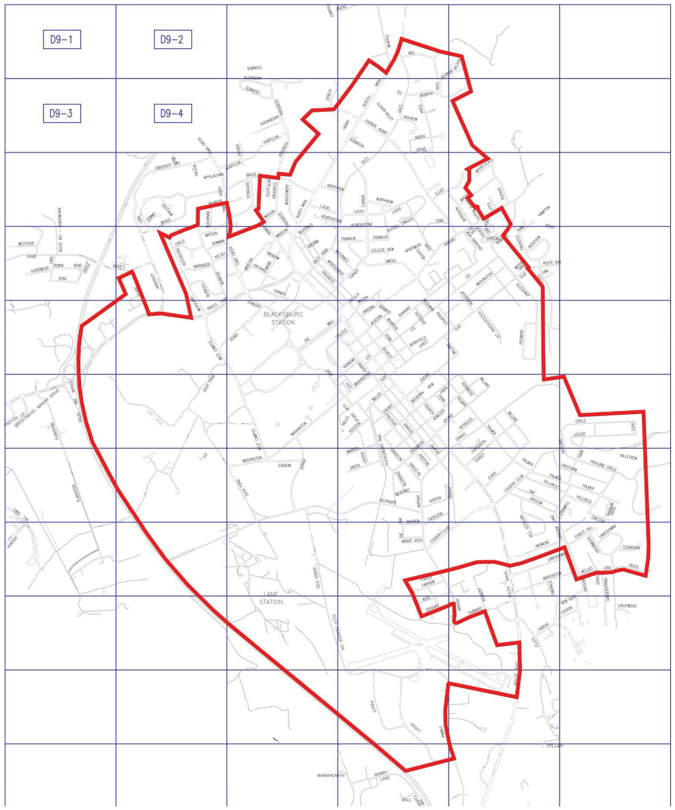


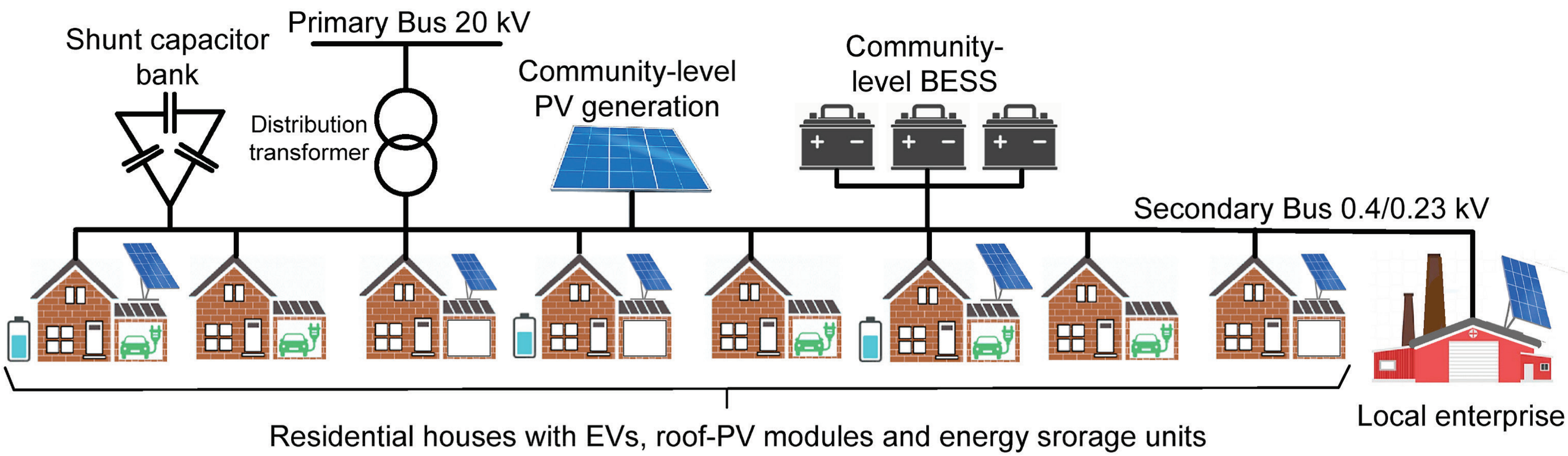
Figure: Virginia Tech Electric Service coverage area.

Target System: Blacksburg / VTES

- College town utility: Campus, residential and commercial loads
- Distribution feeders & substation assets from 4 substations: 66 kV from AEP, 4 substations, 11 kV feeders, local transformers
- AMI + SCADA measurement streams
- DERs (PV, BESS, EV loads)
- Voltage regulation & thermal constraints
- Reliability & outage management priorities

Electric Power Distribution at a Feeder Level

At this level, many small loads come together such as homes, EV charging, rooftop solar. Individually they are simple, but together they become hard to predict. And we often don't have full visibility here.



Source: https://doi.org/10.1016/j.rineng.2022.100592

EV Charging Impact

- Creates new peak demand
- Often clustered in time and location
- Can stress local transformers and feeders
- Requires predictive and coordinated charging management

Renewable Variability

- Solar output changes with cloud cover
- Wind generation is inherently variable
- Supply does not always match demand
- High renewable penetration requires careful planning and intelligent operation

Demand and Behind-the-Meter Supply

- Changing Demand: Campus load, EV charging, future growth
- More Incoming Renewable Energy: Incoming wave of solar systems and storages
- Need for Better Decisions: Planning, operation, and reliability support

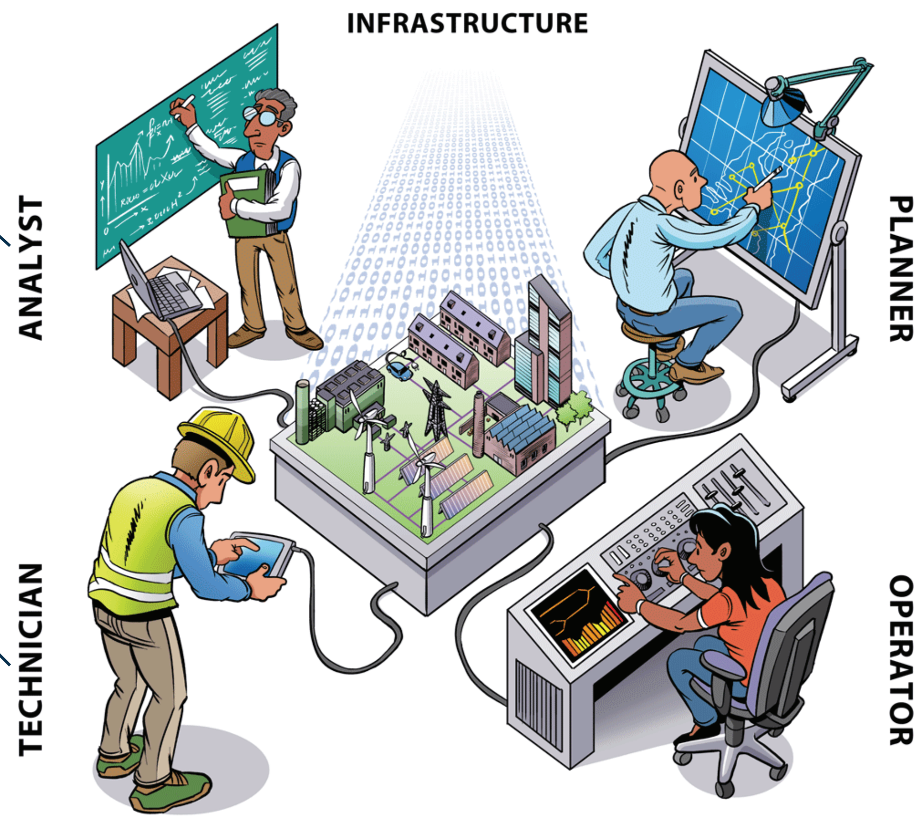
How Can an Intelligent Digital Twin Help

- A continuously synchronized virtual replica of the physical grid integrating:
  - Real-time measurements
  - Physics-based simulations
  - AI/ML predictive analytics
  - Optimization & decision support
- Key Distinction:
  - Simulation → Static
  - Digital Twin → Dynamic
  - Intelligent Digital Twin → Predictive + Prescriptive

Many Uses of Intelligent Digital Twins

- Analyze system behavior and trends
- Detect anomalies and hidden issues
- Develop predictive models

- Identify & diagnose equipment issues
- Perform condition-based maintenance
- Reduce downtime through faster troubleshooting



- Evaluate future scenarios ("what-if")
- Plan grid expansion and upgrades
- Assess integration of renewables & storage

- Monitor system in real time
- Respond to disturbances and maintain stability
- Use decision support for control actions

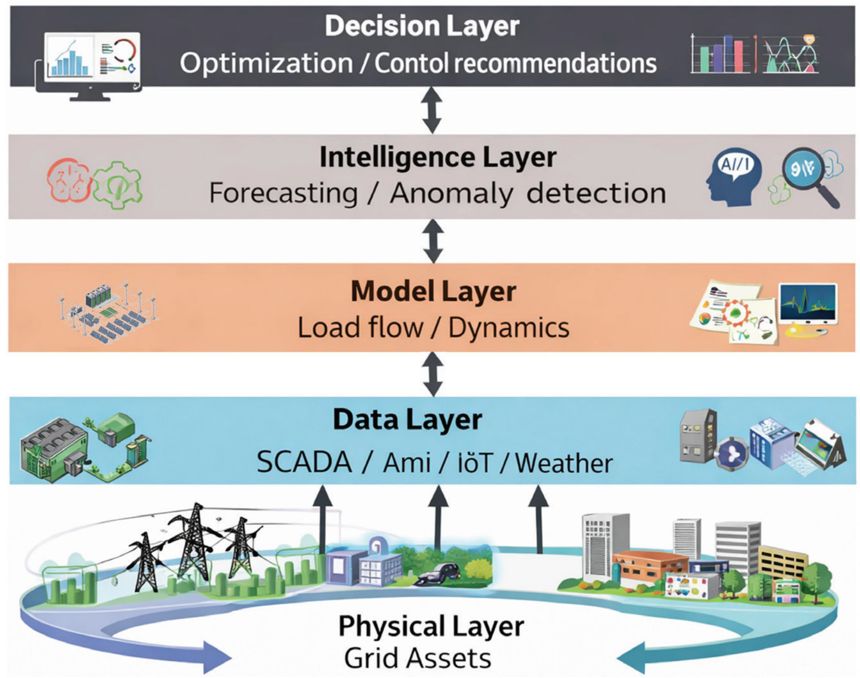
Source: doi: 10.12688/digitaltwin.17435.2

Intelligent Digital Twin Gives VTES a Tool to Simulate Their Operation

- Energy Storage & New Generation: BESS dispatch and renewables integration
- EV charging impact
- Impact of Extreme Demand Events: Football games, concerts (e.g., Metallica 2025)
- System Behavior & Control: Voltage, loading, and stability under different conditions

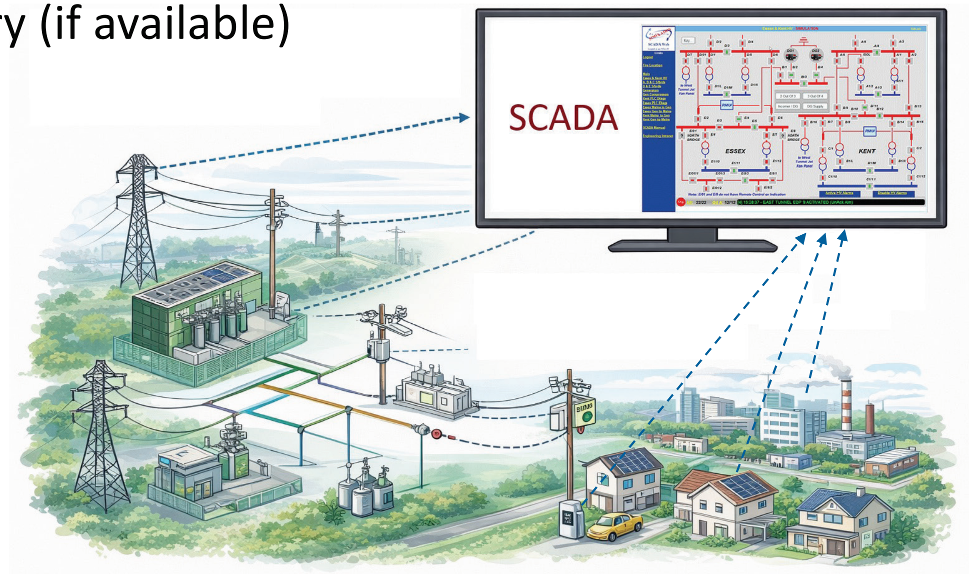
Digital Twin Architecture

- Physical Layer — Grid assets
- Data Layer — SCADA / AMI / IoT / Weather
- Model Layer — Load flow / dynamics
- Intelligence Layer — AI / Forecasting / anomaly detection
- Decision Layer — Optimization / control recommendations



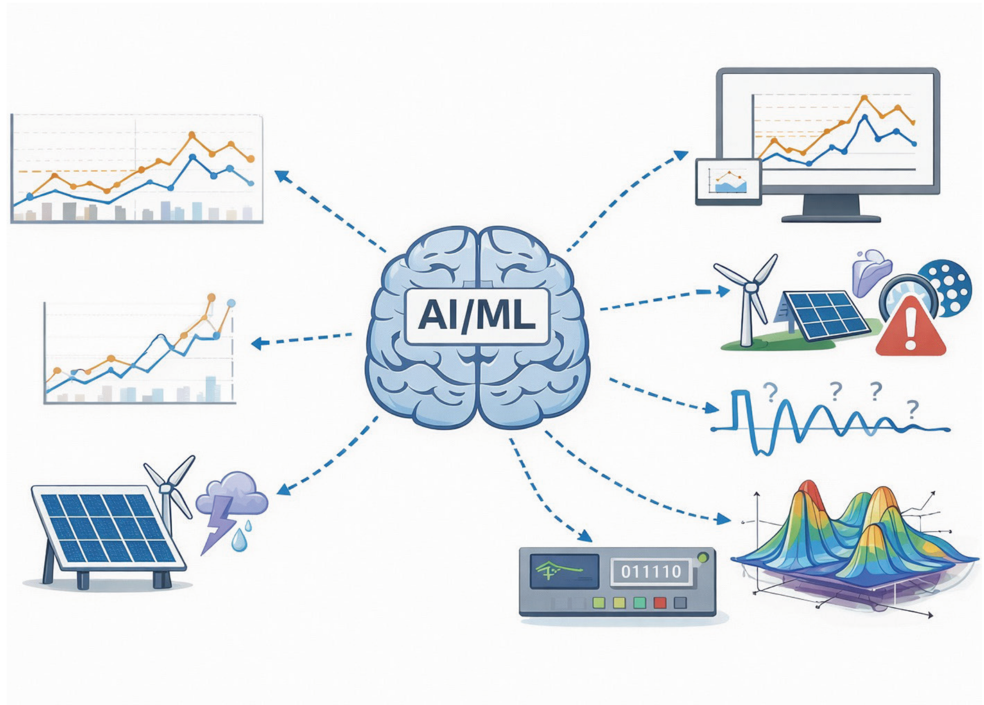
Data and Model Layers (Digital Core)

- Data Layer (Measurement)
  - Supervisory Control And Data Acquisition (SCADA)
  - AMI
  - DER telemetry (if available)
- Model Layer (Network model)
  - Feeder topology & impedances
  - Transformer / regulator / capacitor models
  - Switch & protection status



Intelligence Layer

- AI/ML Enhancements:
  - Short-term load forecasting
  - PV / DER output forecasting
  - Anomaly & bad-data detection
  - Oscillation / abnormal loss detection
  - Surrogate models for fast optimization
- Principle: AI augments physics — does not replace it



Physical and Decision Layers

- Physical Layer (Grid Assets):
  - Feeders, transformers, substations
  - DERs (solar, BESS, EV loads)
  - Relays, switches and other actual elements
- Decision Layer (Optimization & Control):
  - BESS dispatch and peak reduction strategies
  - Volt/VAR optimization and DER coordination
  - Reliability-aware switching and control actions

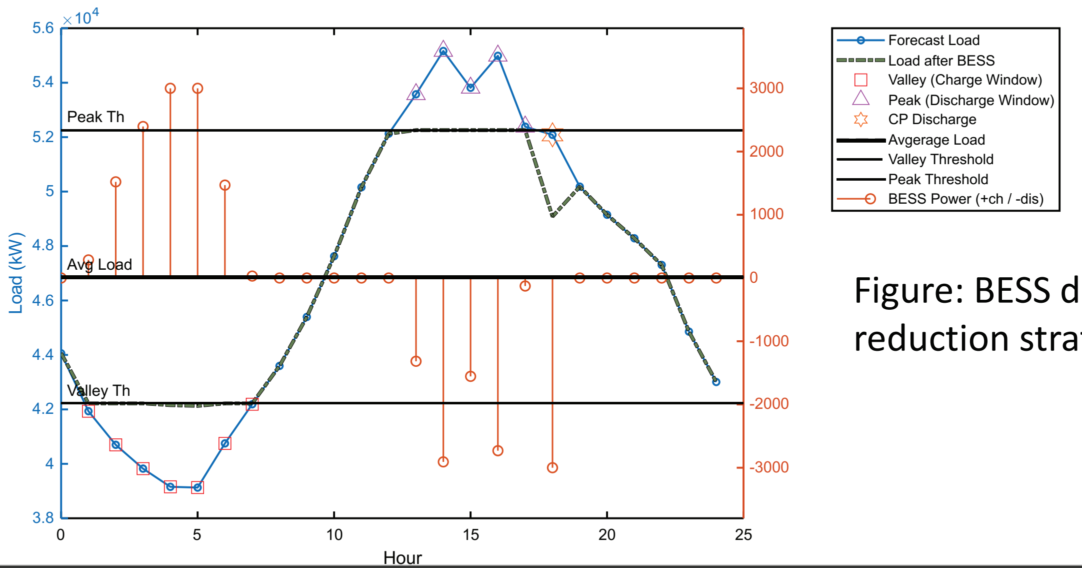
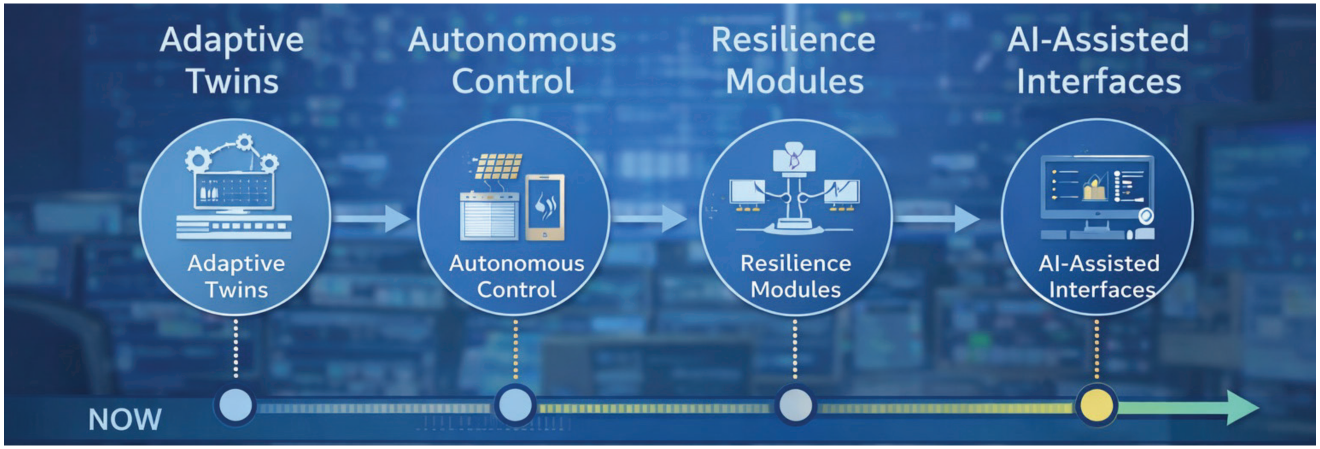


Figure: BESS dispatch and peak reduction strategies for VTES.

Future Evolution

- Self-learning adaptive twins
- Closed-loop DER/BESS control
- Resilience & cascading failure modules
- Federated multi-feeder/ multi-utility twins
- AI-assisted operator interfaces



Takeaway Message

- An Intelligent Digital Twin Enables:
  - Accurate real-time grid replication
  - Predictive system behavior insight
  - Prescriptive, constraint-aware decisions
  - Enhanced reliability, economics, resilience

Thank You

Saifur Rahman, 2023 IEEE President
s.rahman@ieee.org
Web: www.srahman.org