

# Space-Based Energy Resilience Changing Lives and Labs

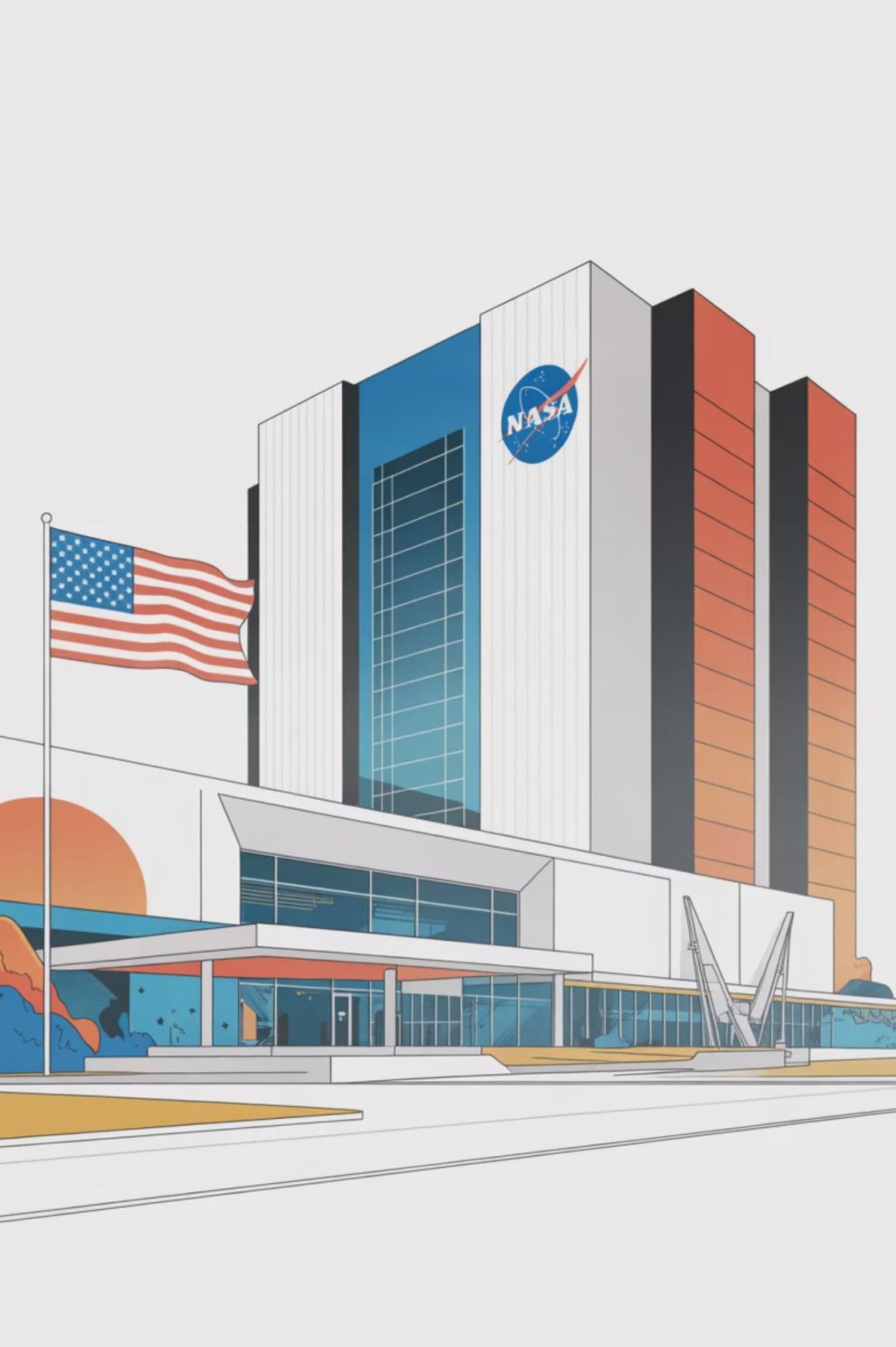
Farzad Ferdowsi, Ph.D.  
Associate Professor  
Electrical and Computer Engineering Dept.

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**Engineering**





# LaSPACE: Powering Innovation Through Partnership

## Research Enhancement Awards

Two REA grants enabled groundbreaking collaboration with NASA Stennis Space Center and NASA Glenn Research Center

## Summer 2025 at GRC

Full-time visiting researcher position at NASA Glenn's Autonomous Power Controls Lab, working directly with AMPS system

## Building Bridges

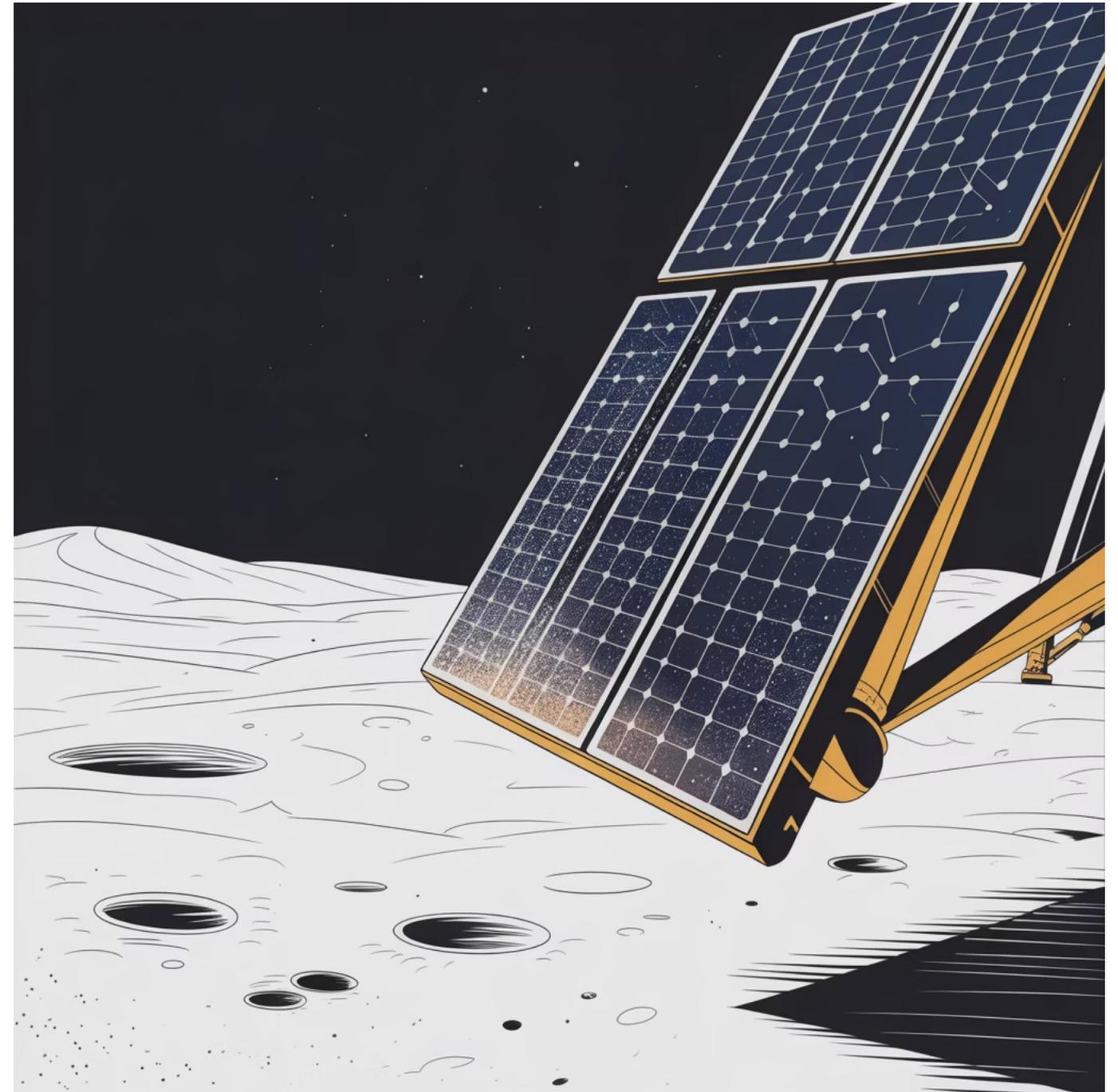
Transforming Louisiana researchers into NASA collaborators, advancing both space exploration and terrestrial applications

# The Challenge: Power Systems Beyond Earth

## Space Environments Are Unforgiving

- Lunar dust accumulation on solar panels
- Extreme temperature fluctuations (-173°C to 127°C)
- Radiation exposure degrading components
- Communication delays up to 44 minutes
- Zero tolerance for failure

Traditional power system approaches fail in these extreme conditions. We need intelligent, autonomous solutions that can predict, adapt, and survive.





# Digital Twin: From NASA's Apollo to Today's Artemis

## 1960s: Apollo Era

NASA pioneers "live model" concept for mission-critical systems

1

## 2024: Artemis Program

Digital twins essential for sustainable lunar presence and Mars missions

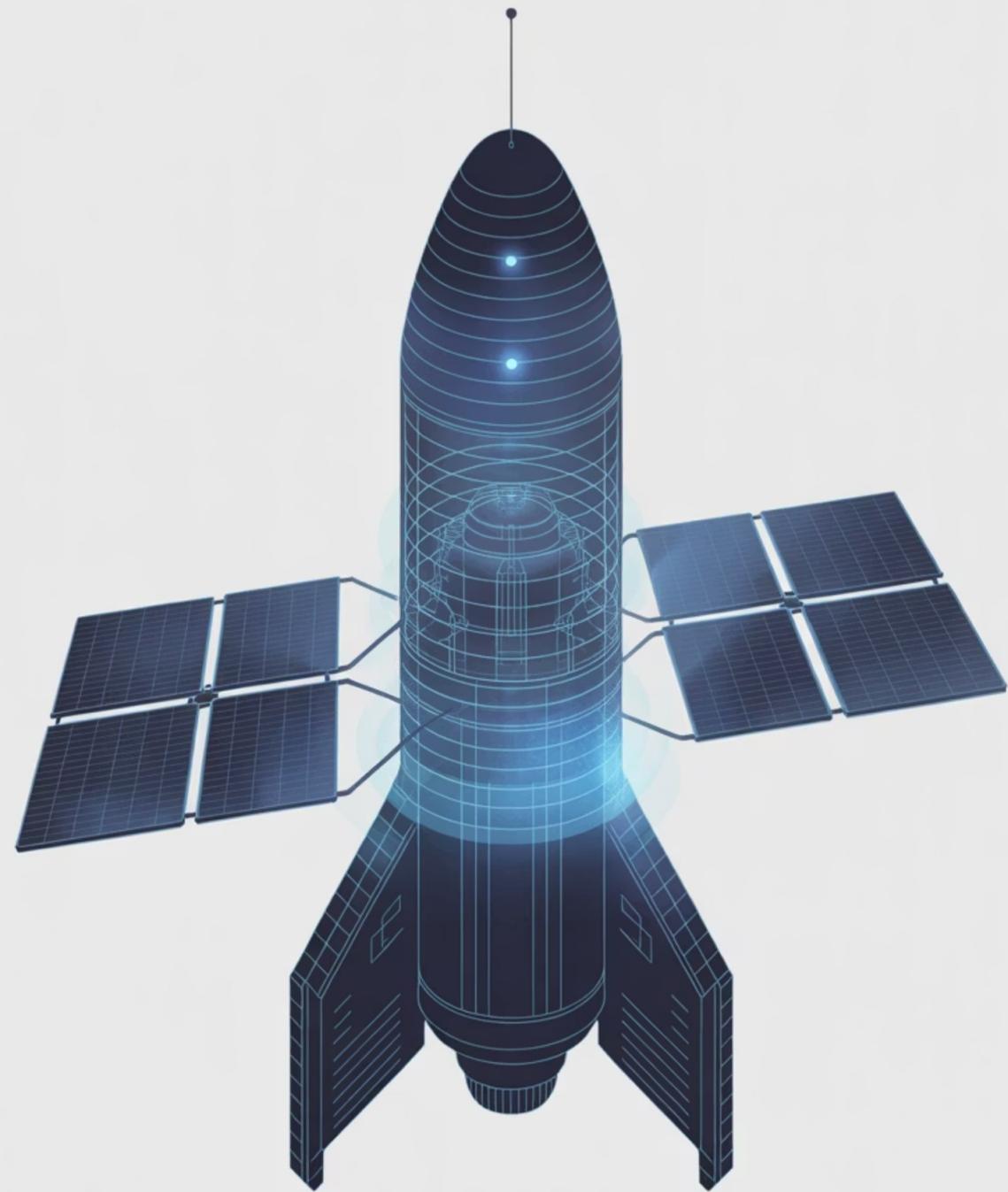
3

## 2020s: Digital Twin Revolution

Advanced computing enables real-time, high-fidelity virtual replicas

2

Our work builds on NASA's legacy, applying cutting-edge digital twin technology to solve tomorrow's space power challenges.



# Digital Twin: Your System's Virtual Counterpart

01

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## Real-Time Replication

Virtual model mirrors physical system behavior with millisecond precision

02

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## Predictive Intelligence

Anticipates failures before they occur using physics-based modeling and AI

03

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## Safe Testing Ground

Run dangerous "what-if" scenarios without risking actual hardware

04

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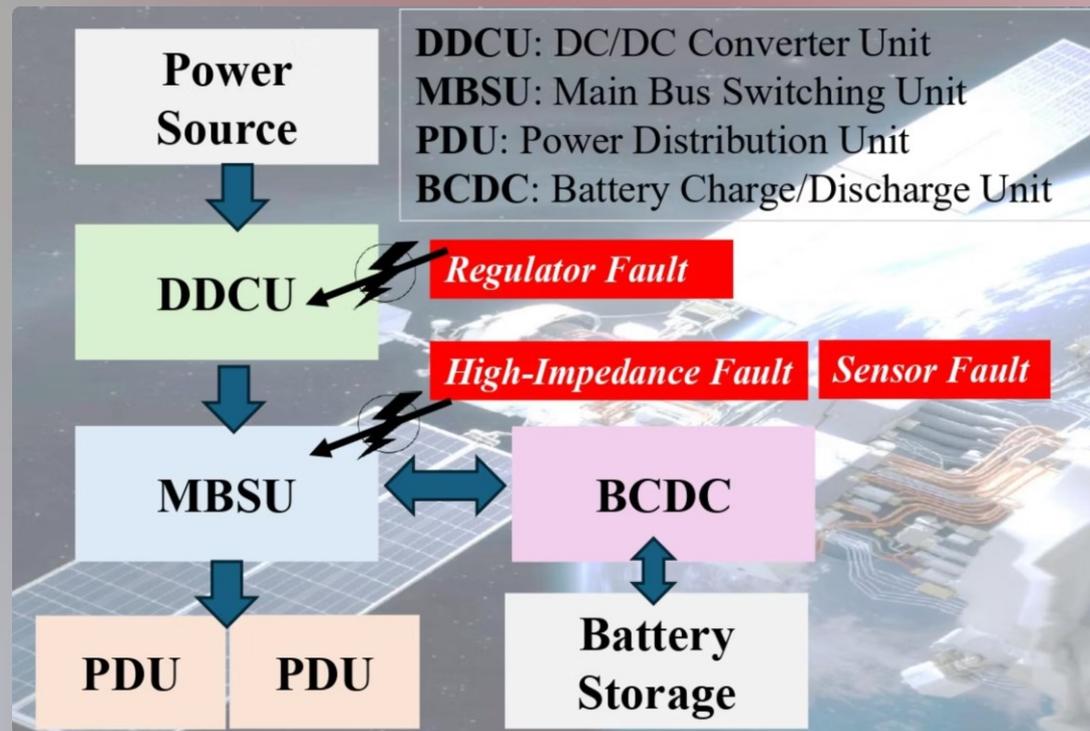
## Autonomous Decision-Making

Enables systems to respond intelligently when human intervention is impossible

# NASA AMPS: A Testbed for Innovation

## Advanced Modular Power System (AMPS)

- An advanced power system for future space missions
- Crucial for supporting lunar surface habitats
- Employs a highly modular and scalable design
- Ensures robust and reliable power distribution
- Designed with fault tolerance for critical space environments



# Building the Digital Twin: Architecture

**1**

## Physical Layer

Real hardware: sensors, converters, loads generating operational data

**2**

## Digital Layer

Virtual model replicating system behavior using Typhoon HIL platform

**3**

## Communication

Low-latency data exchange via certain protocols

**4**

## Data Layer

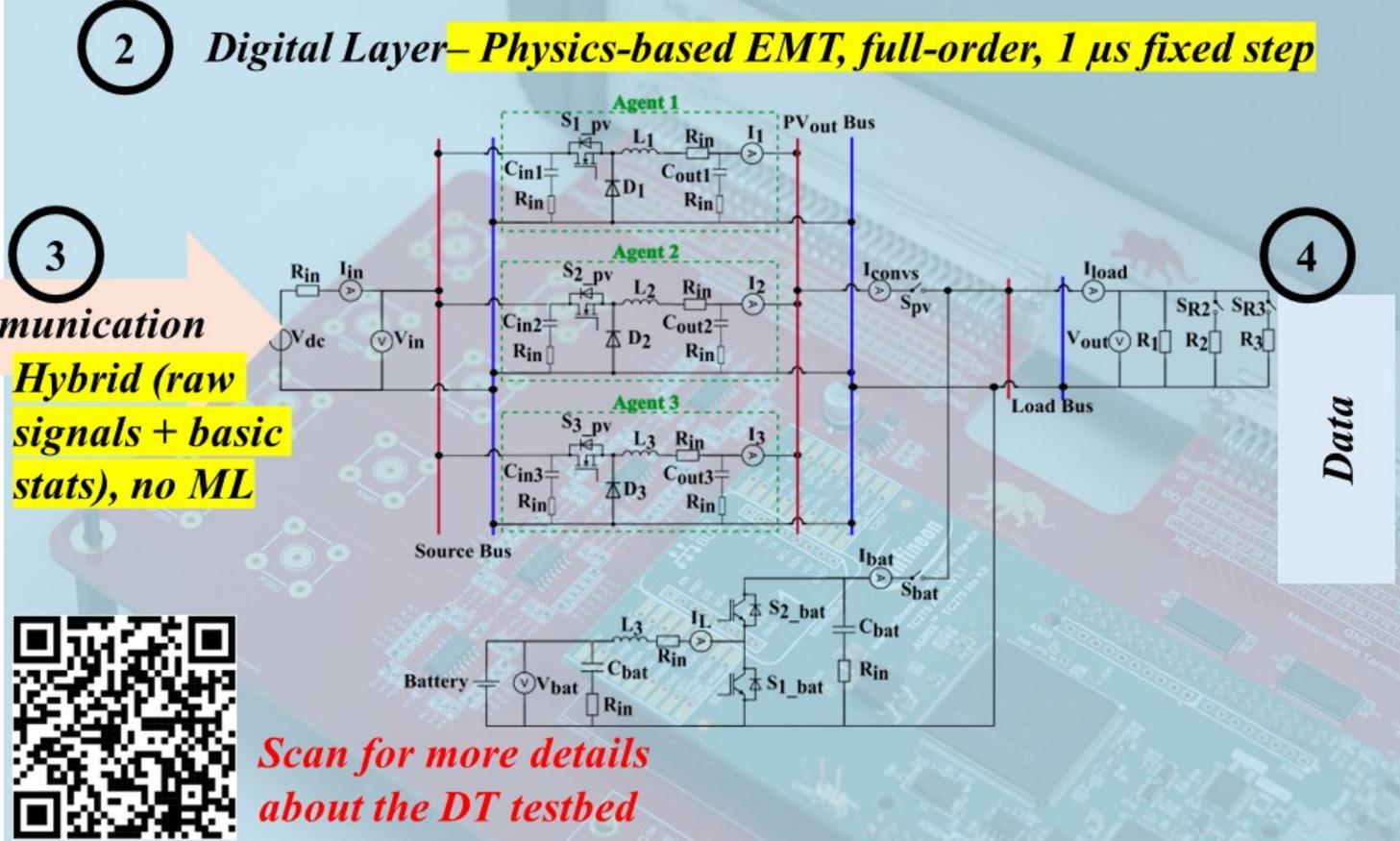
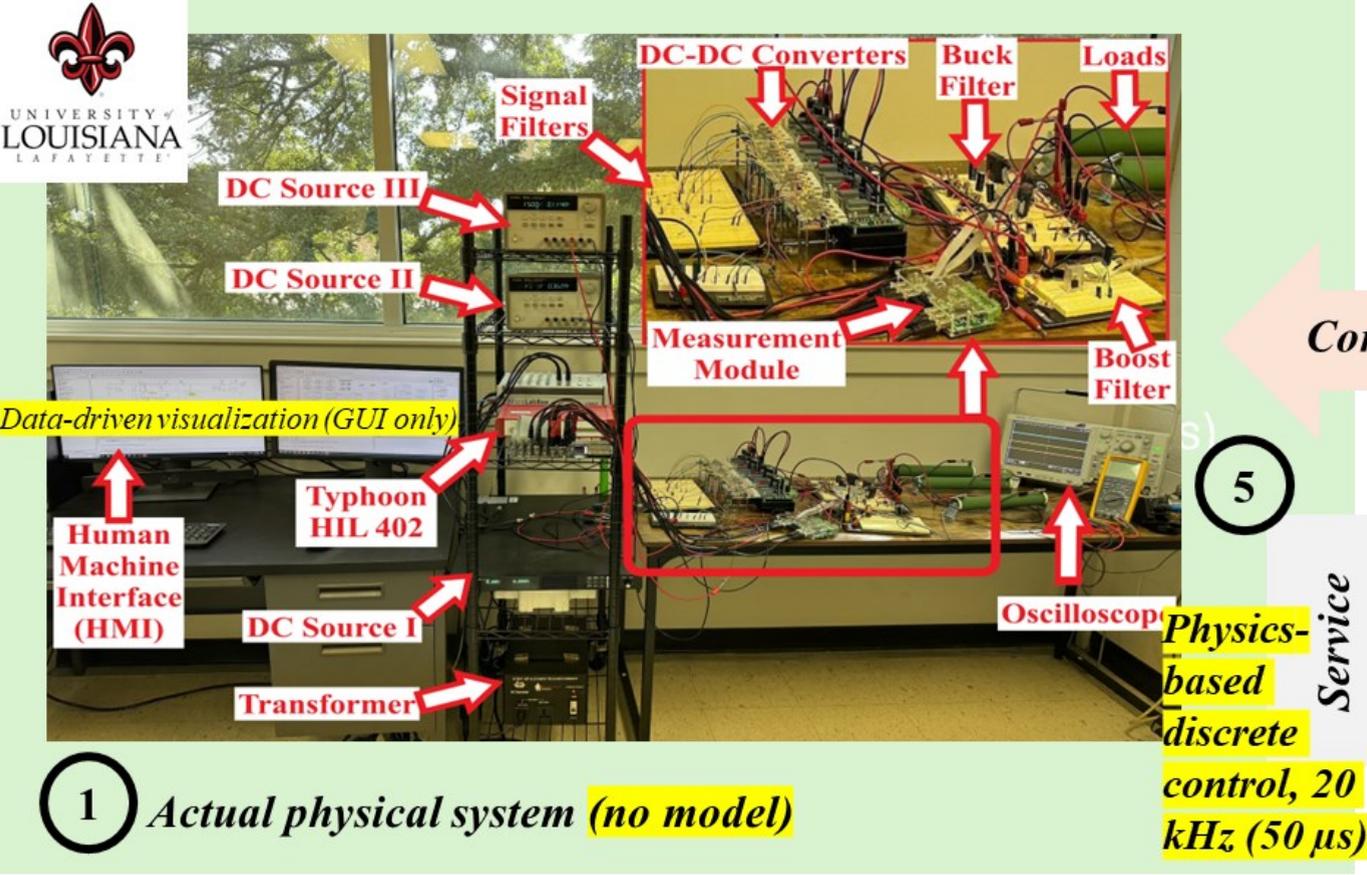
Real-time streams integrated with historical logs and analytics

**5**

## Service Layer

Actionable insights: predictive maintenance, operator training, control

# DC Microgrid Digital Twinning at UL Lafayette



**5** Service  
Physics-based discrete control, 20 kHz (50  $\mu$ s)

This image showcases the physical DC microgrid testbed at the University of Louisiana at Lafayette, alongside its corresponding digital twin implementation. The setup allows for real-time monitoring, control, and simulation of the microgrid's components, facilitating advanced research in resilient power system operations and digital twin-driven health management.

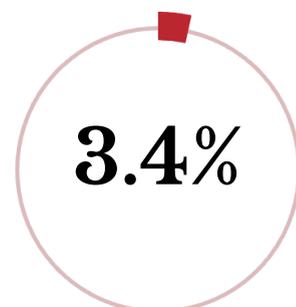
# Validating Fidelity: Can We Trust the Twin?

## Rigorous Testing Protocol

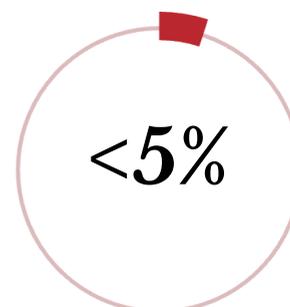
- Multiple voltage configurations tested
- Normal and emergency scenarios
- Dynamic load variations
- Fault injection studies
- Real-time synchronization verification



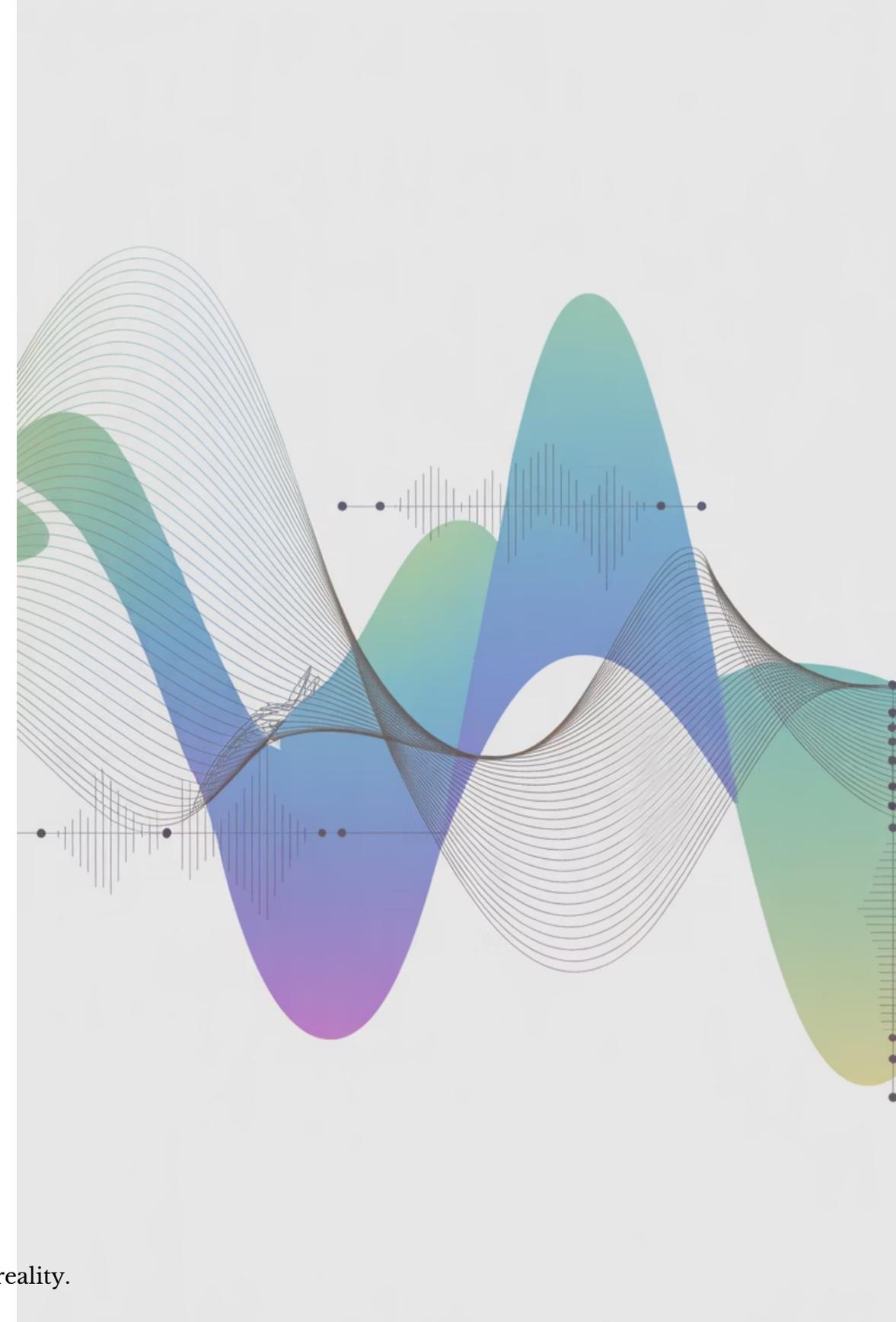
Best RMSE  
24V configuration



Worst RMSE  
12V configuration



Target Met  
All scenarios



Root Mean Square Error (RMSE) consistently below 5% across all operating conditions proves our digital twin accurately mirrors reality.

# Emergency Response: When Solar Fails

1

## Dust Storm Hits

Solar PV output drops from 48V to 2V in seconds

2

## Instant Detection

Digital twin identifies power shortage before voltage collapse

3

## Autonomous Switch

Battery system activated, PV isolated, load maintained at 24V

4

## Mission Continues

Zero interruption to critical systems

# Intelligent Fault Detection: The Entropy Breakthrough

## NASA APC Collaboration

Working with NASA's Autonomous Power Controls team, we developed entropy-based fault detection for AMPS

**37.5%**

Separability Gain

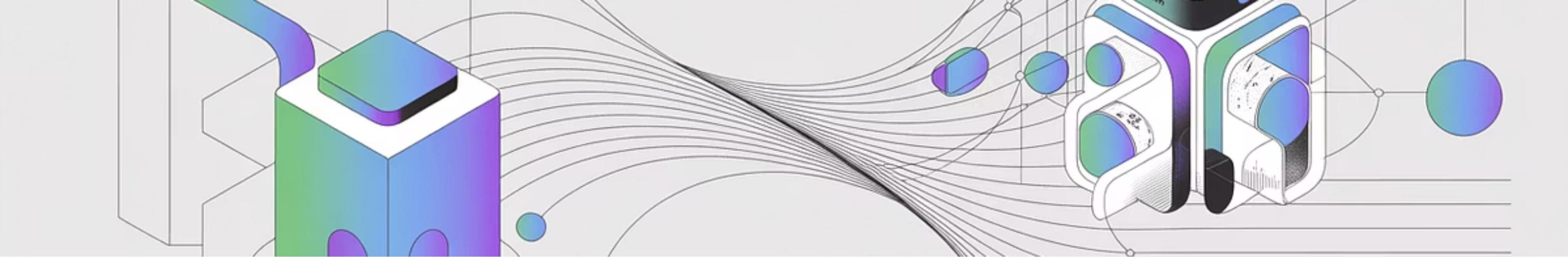
Correlation-based metric

**194.6%**

Index Improvement

Separability index





# Transfer Learning: Teaching AI with Digital Twins



## High-Fidelity Data Generation

Digital twin creates perfect training datasets without risking hardware



## AI Model Training

Machine learning algorithms learn fault patterns from symptom data

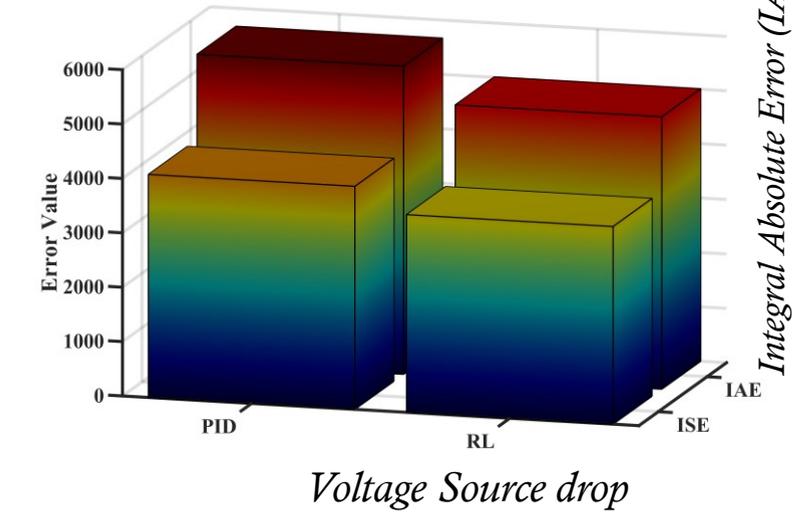
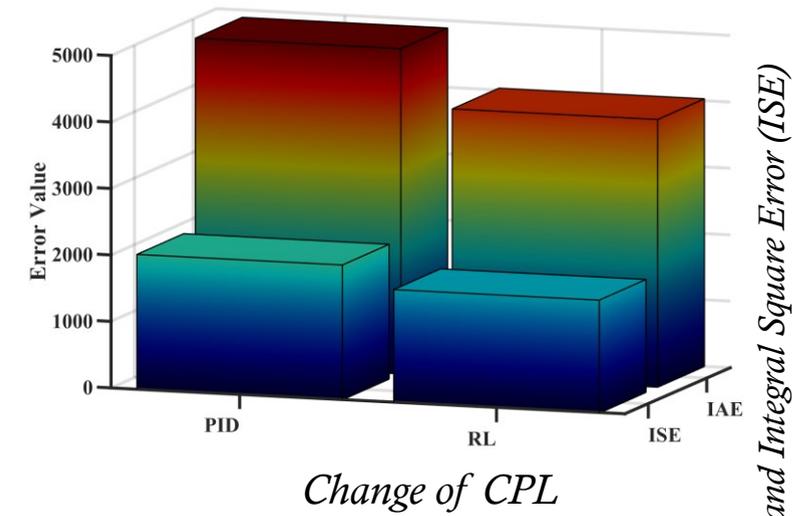
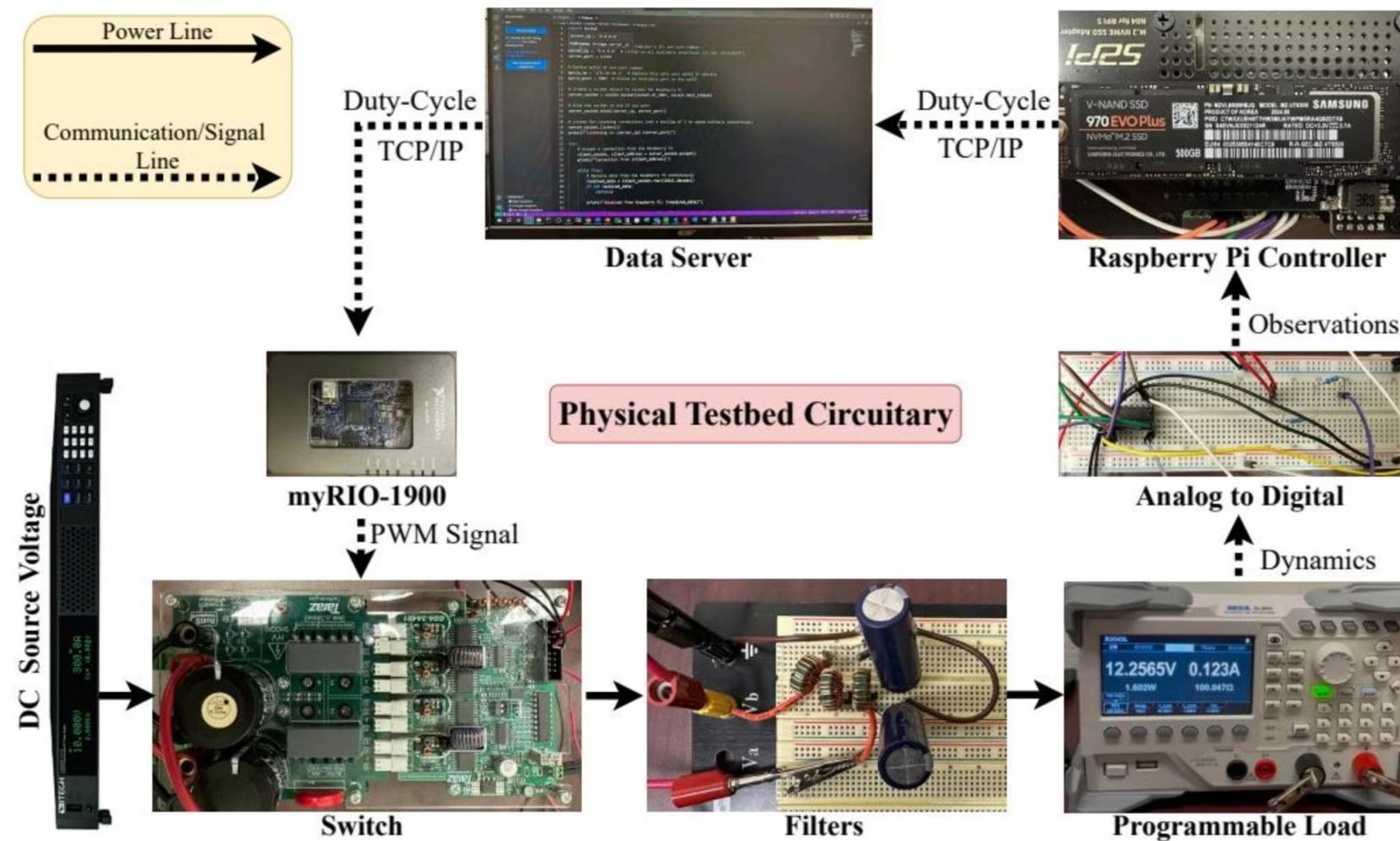


## Seamless Deployment

Trained models transfer to physical system with minimal fine-tuning

Our reinforcement learning approach achieved 97% fault classification accuracy using digital twin-generated data, eliminating the need for dangerous real-world fault testing.

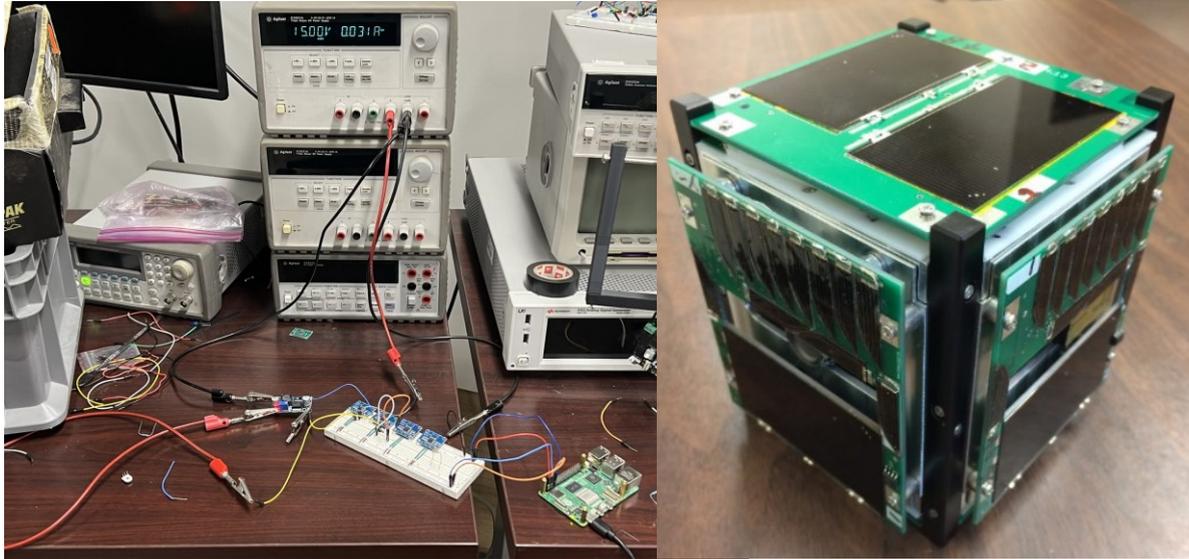
# Real-World Impact: Battery-Integrated DC Microgrid



## Terrestrial Testbed Results

- Voltage source drop: 37.5% faster recovery than PI control
- Constant power loads: Mitigated oscillations during transitions
- CHIL: Proves embedded deployment feasibility

# CubeSat Digital Twin: Savion's Mission



## Miniature Spacecraft, Maximum Challenge

- CubeSat power system design
- Power management
- Battery charge/discharge strategies
- 5V and 3.3V load interfaces and DC-DC converters
- What-if scenario planning

01

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### Characterize PV Array

Using solar emulator to map performance curves

03

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### Build Digital Twin

Virtual CubeSat for safe testing

02

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### Design Robust Controller

Running what-if scenarios

04

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### Develop Response Plans

Advanced control schemes for autonomy

# From Space to Earth: Terrestrial Applications

## **EV Charging Infrastructure**

Battery management and grid integration strategies proven in space now optimize terrestrial charging networks

## **Critical Facility Backup**

Hospitals and data centers benefit from space-grade resilience and autonomous fault response

## **Remote Microgrids**

Off-grid communities gain reliable power using control strategies developed for lunar habitats

# Smart Switching: User-Defined Resilience

## Resilience-Oriented Settings

Operators define priorities: critical loads, backup sequences, voltage thresholds, response times

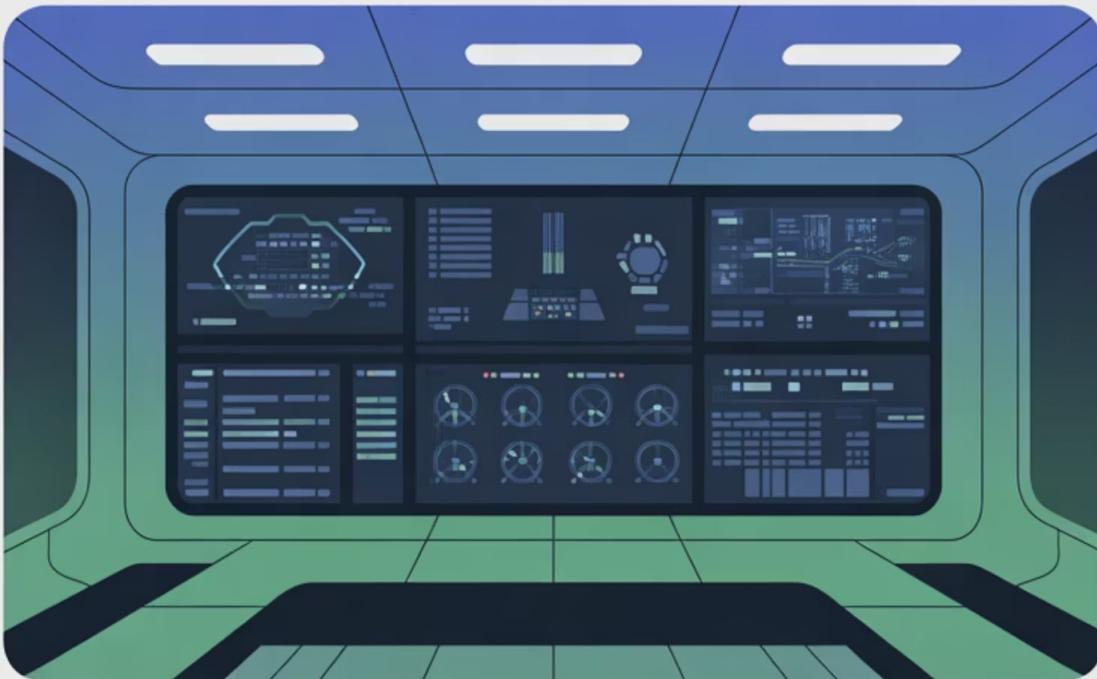
## Intelligent Decision Engine

Digital twin evaluates scenarios in real-time, selecting optimal switching strategy based on user preferences

## Adaptive Execution

System automatically reconfigures power distribution to maximize mission success probability

This isn't just automation...it's intelligent autonomy that respects human priorities while responding faster than any operator could.



# The Six Challenges

## 1. Fidelity Standards

Established quantitative metrics for digital twin accuracy

## 2. Model Selection

Hybrid physics-based and data-driven approach

## 3. Digital Abstraction

Balanced detail vs. computational efficiency

## 4. Resource Integration

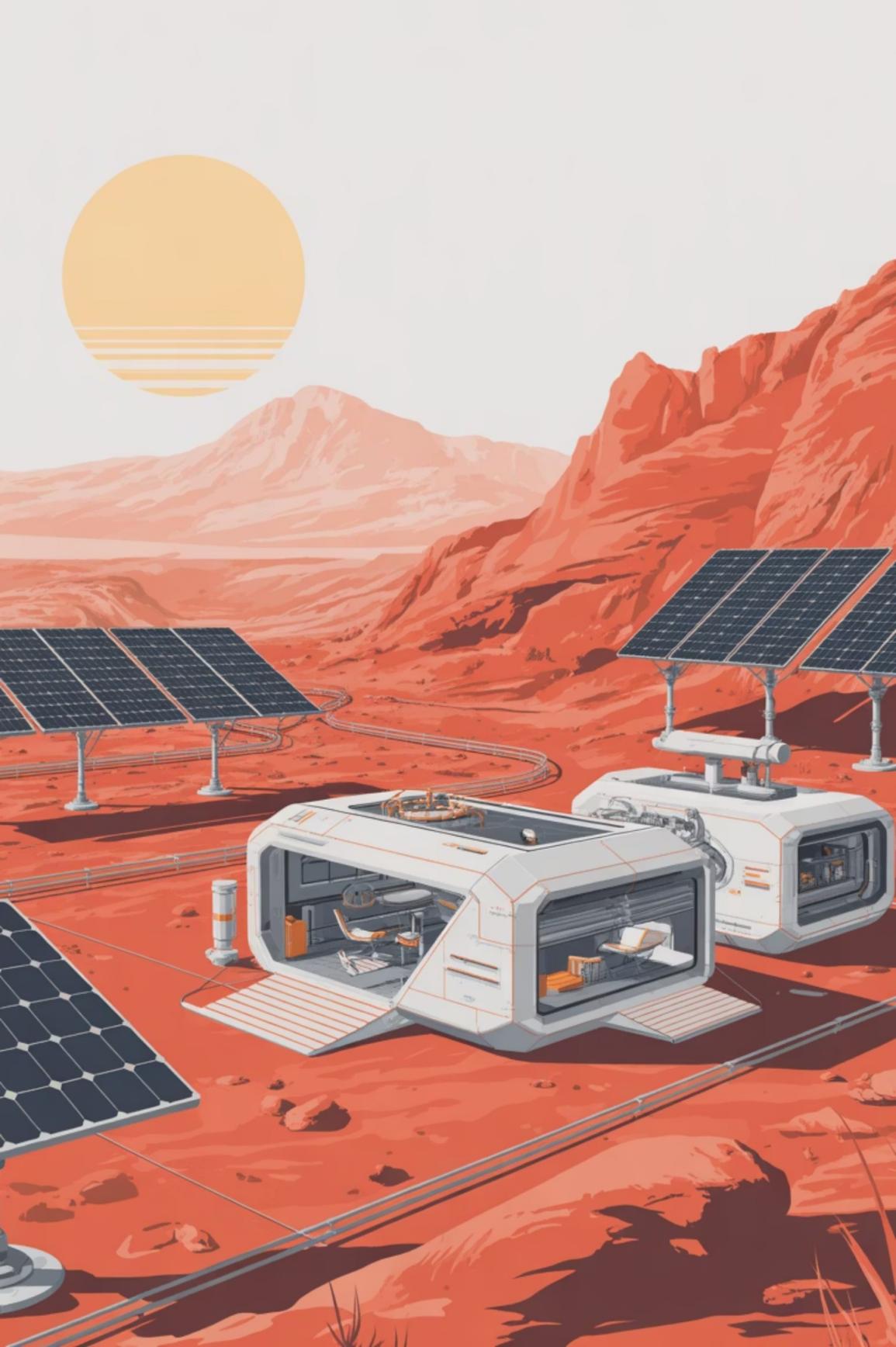
Unified legacy and modern systems

## 5. Multi-Physics

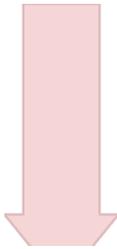
Coupled electrical-thermal-mechanical modeling

## 6. Live Twinning

Real-time synchronization under 50ms latency

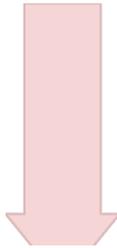


# What's Next: The Roadmap Forward



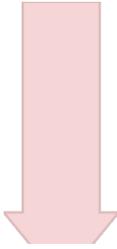
## Standardization

Develop industry-wide fidelity metrics and validation protocols for power system digital twins



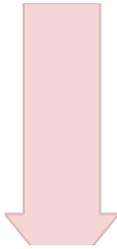
## Scalability

Extend from single microgrids to multi-microgrid systems and utility-scale applications



## AI Integration

Advanced machine learning for predictive maintenance and autonomous optimization



## Fully Autonomous

Prepare digital twin technology for deep space missions with long communication delays and no physical access

# Thank You: Questions & Discussion

## Contact Information

[ferdowski@louisiana.edu](mailto:ferdowski@louisiana.edu)

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