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Hardware-In-the-Loop (HIL) from a System Integrator's Perspective

April 23rd, 2024

Jim Cleveland

What is a HIL for a System Integrator?

For a System Integrator, a Hardware-In-the-Loop (HIL) system is a **simulation tool** that can be used for many things throughout the entire Integration Process

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Today's Goals

1. IHI Terrasun Background
2. Jim Cleveland Background
3. Hardware-In-the-Loop (HIL)
4. Simulation and Test Environments
5. Summary

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IHI Corporation

Our Parent Company

IHI Corporation has been a leader in the industrial sector since 1853 and has headquarters in Tokyo, Japan. It is organized into the following four Divisions:

- Resources, Energy, and Environment
- Social Infrastructure and Offshore Facilities
- Industrial Systems and General-Purpose Machinery
- Aero Engine, Space and Defense

$8B in Revenue

28,000 Employees

170 Years of Operation

IHI Corporation & IHI Terrasun Solutions

IHI Terrasun Solutions with headquarters
in Chicago, IL
is a subsidiary of IHI Corporation in the
Resources, Energy, and Environment division.

80GW operational power plants

2.5GWh BESS deployed

20 YR+ long-term service wraps

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Jim Cleveland Background

Jim Cleveland Background

Automotive

Engine Simulation, Analysis, and Testing

- Pre-Processing and Post-Processing
  - One-Dimensional Gas Dynamics
  - Finite Element Analysis (FEA)
  - Computational Fluid Dynamics (CFD)
  - Internal Combustion Engine Test Cells

Jim Cleveland Background

Industrial

Industrial Controls

- Real-Time Embedded Controls Design/Development
- Hardware and Software Design
- Testing and Reviews
  - Code Reviews
  - Test Boxes
  - Lab Testing
  - Factory and Automated Board Testing
  - Field Testing

Jim Cleveland Background

Aerospace

Aerospace Controls

- Controls Design and Development
- RTCA/DO-178B
- Validation and Verification (V&V)
  - Hardware-In-the-Loop (HIL) Testing
  - Vibration Testing
  - Environmental Testing
  - High Potential (HIPOT) Testing
  - …

Jim Cleveland Background

Energy

Energy Controls

- Controls Design and Development
- Electrical Modeling and Simulation
- Hardware-In-the-Loop (HIL) Testing
- Lab Testing
- Field Testing
- Commissioning

Jim Cleveland Background

Automotive

Aerospace

Industrial

Energy

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Hardware-In-the-Loop (HIL) Project Timing

- Proposals
- Development
- Installation
- Commissioning
- Service and Support

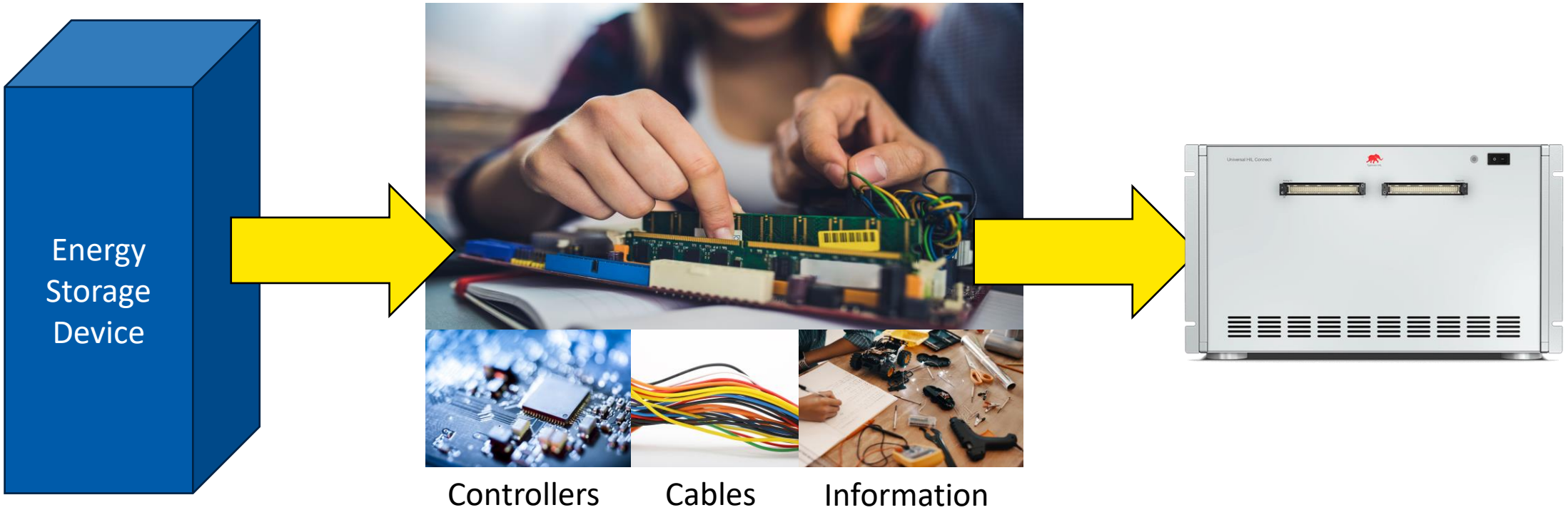
Hardware-In-the-Loop (HIL) Uses

- New Device Integration and Testing
- New Feature Development and Testing
- Controller Behavior Testing
- Controller Timing Testing
- Training
- Field Debugging and Support
- … and more

What type of In-the-Loop (IL) System?

Although there are many types (FIL, MIL, PIL, SIL, …), let's focus on the:

Controller Hardware-In-the-Loop (C-HIL)

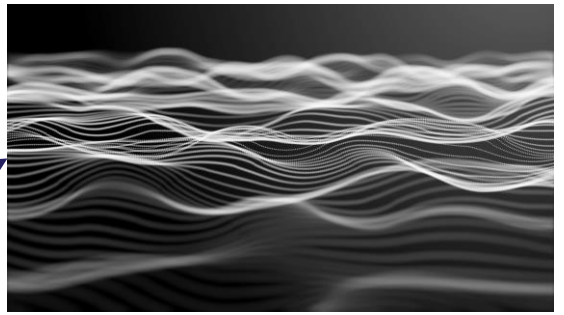


Controller Hardware-In-the-Loop (C-HIL)

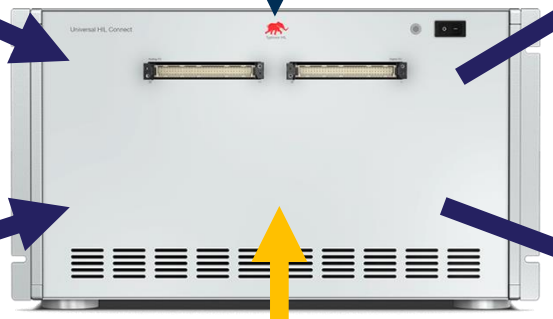
Analog Input (AI)

Communications

Analog Output (AO)



Digital Input (DI)



Auxiliary Power

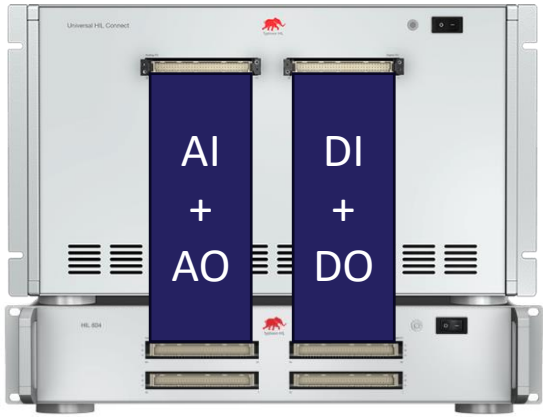
Digital Output (DO)

Hardware-In-the-Loop (HIL) Simulator

Real-Time Electrical Simulator

- Analog Input/Output (I/O) Signals
- Digital Input/Output (I/O) Signals
- Communications (Modbus, CAN, …)
- Simulation Step Time = 1 [microsecond]

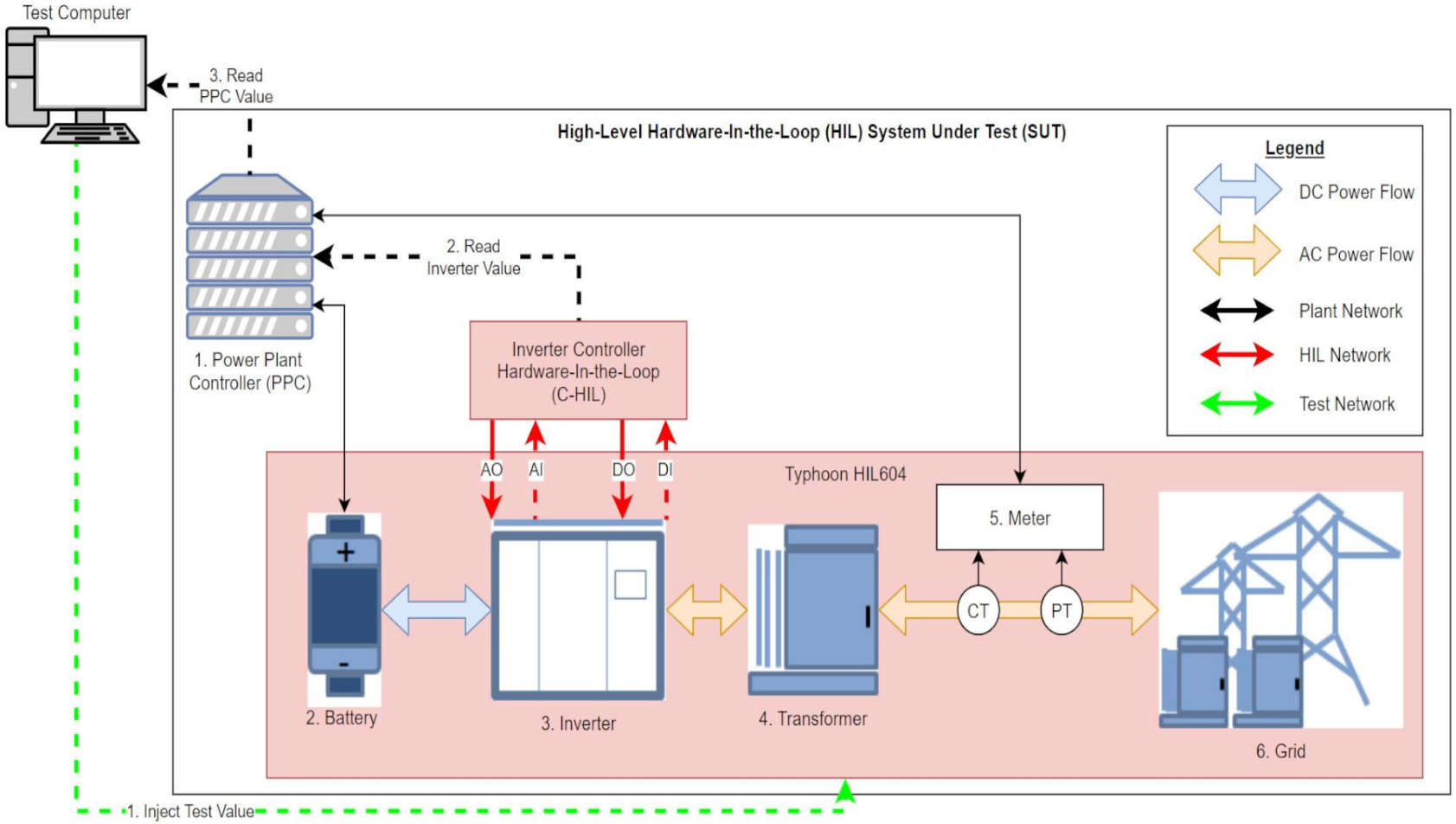
Controller Hardware-In-the-Loop (C-HIL) Test System



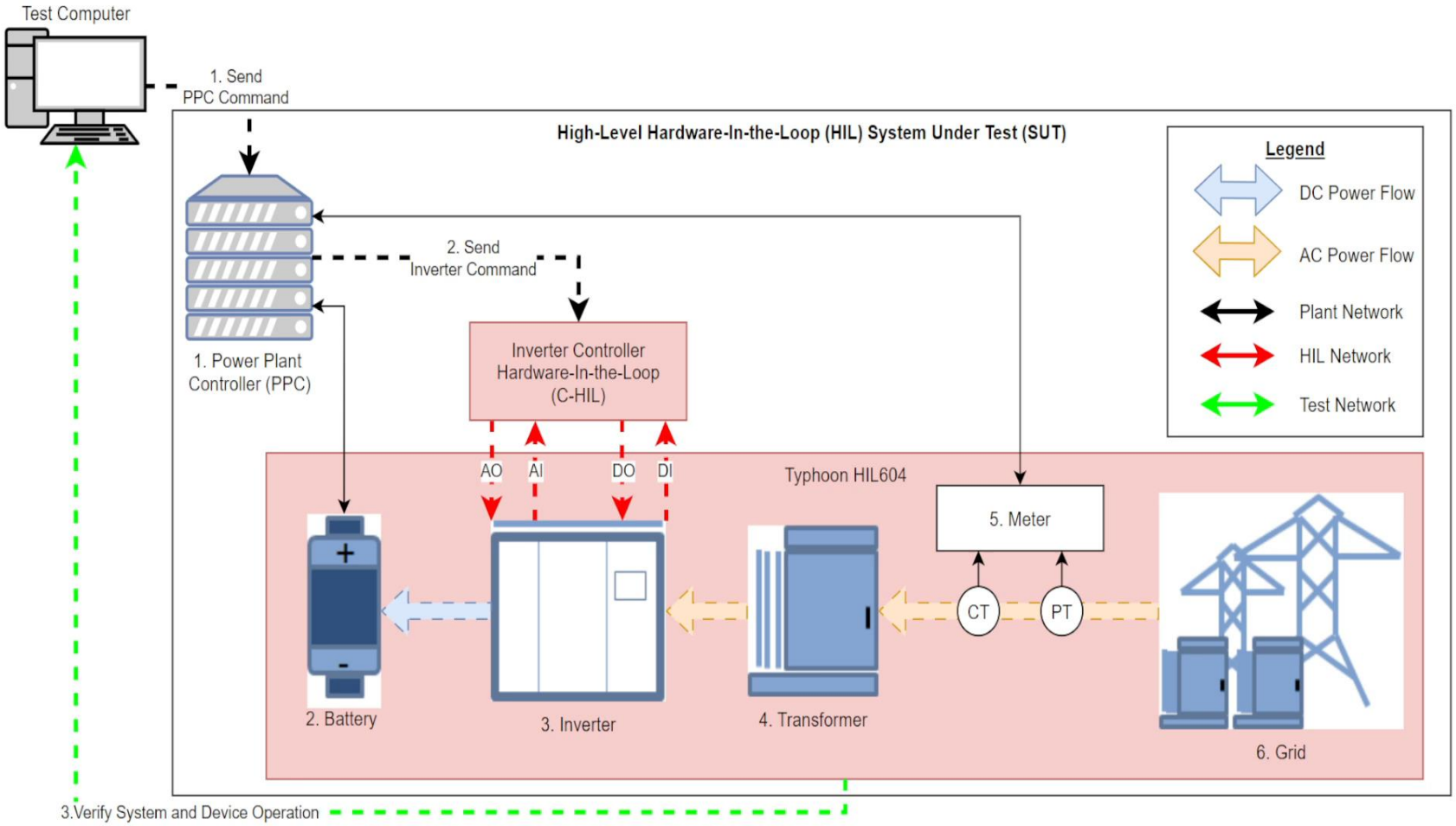
Types of Testing

- Status Testing
- Operational Testing
- Failure and Recovery Testing
    - Communication Failures, Power Failures, Signal Failures, …
    - Ground Faults, Shorting Phases to one Another, Frequency Fluctuations, …
    - Over/Under Voltage, Over Current, Over/Under Temperature, …

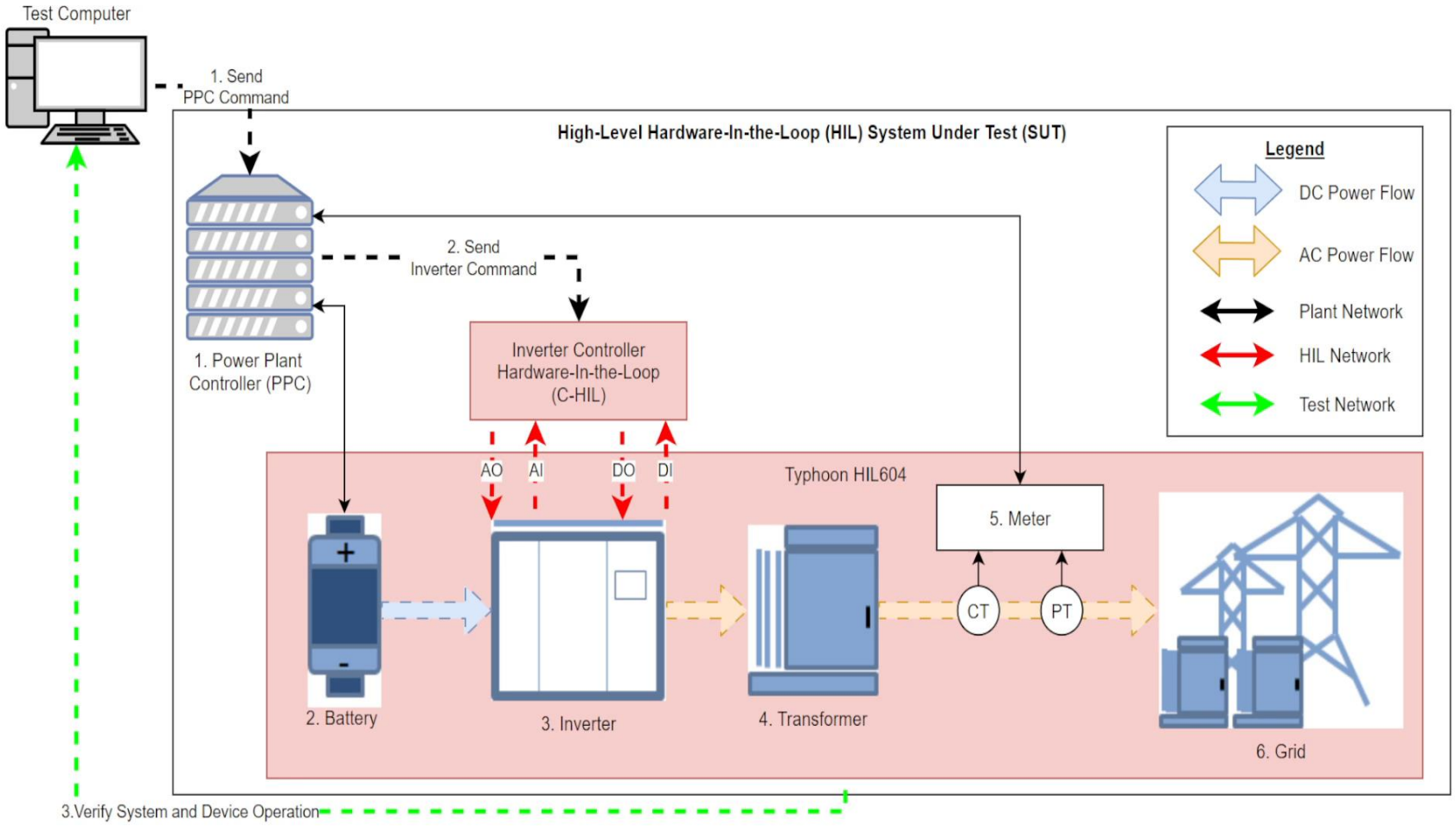
HIL Status Testing



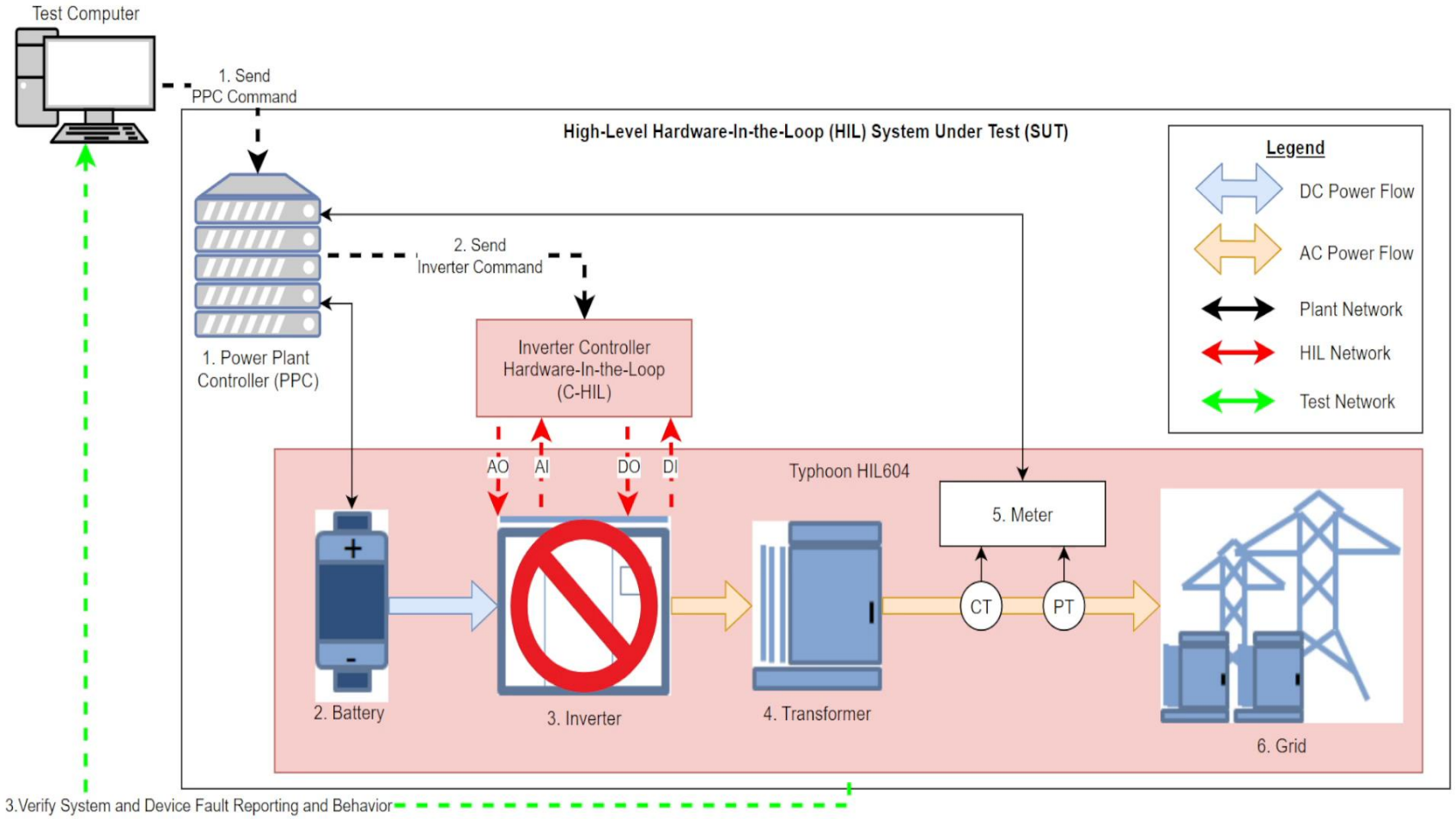
HIL Operational Testing (Charge)



HIL Operational Testing (Discharge)



HIL Failure and Recovery Testing



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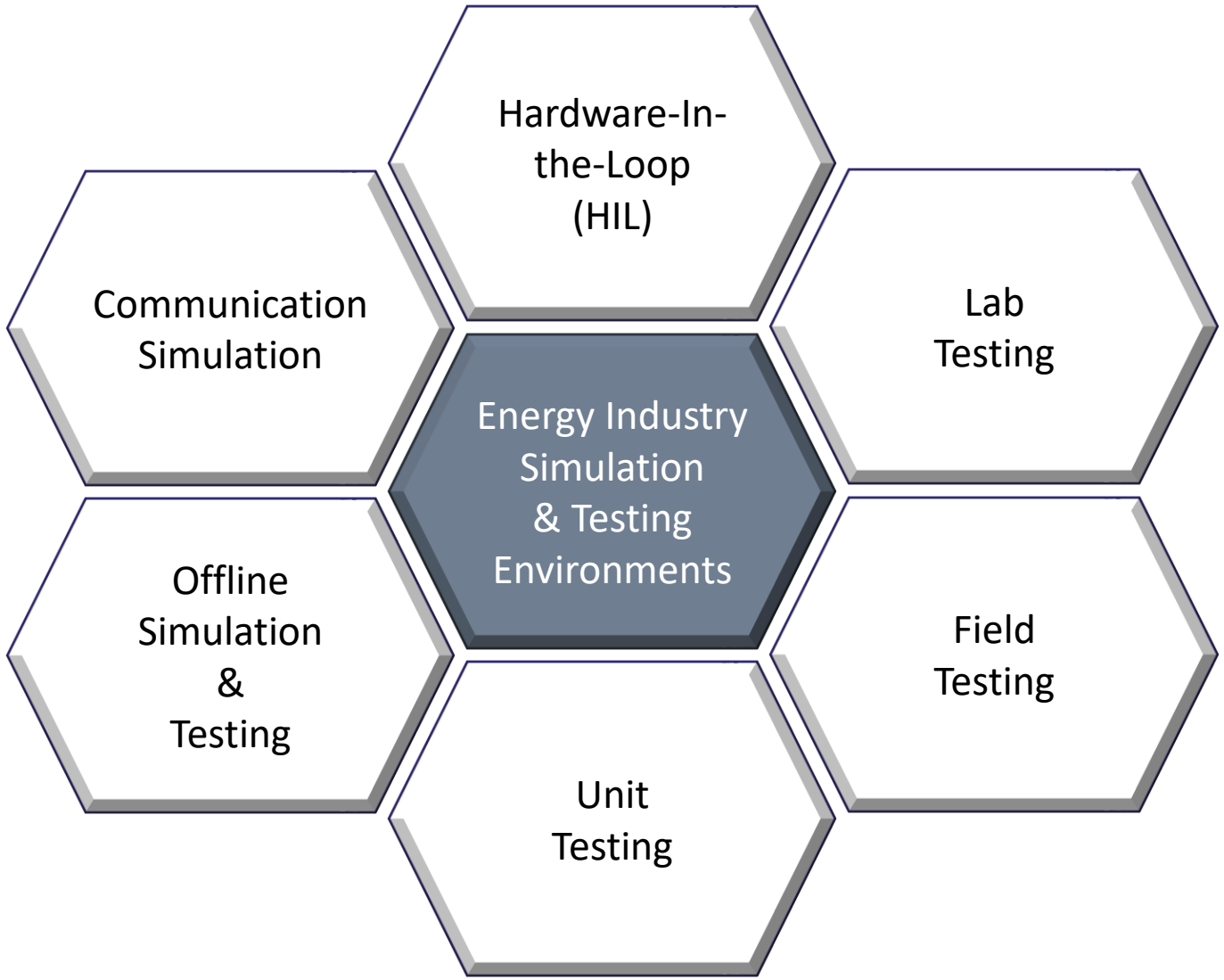
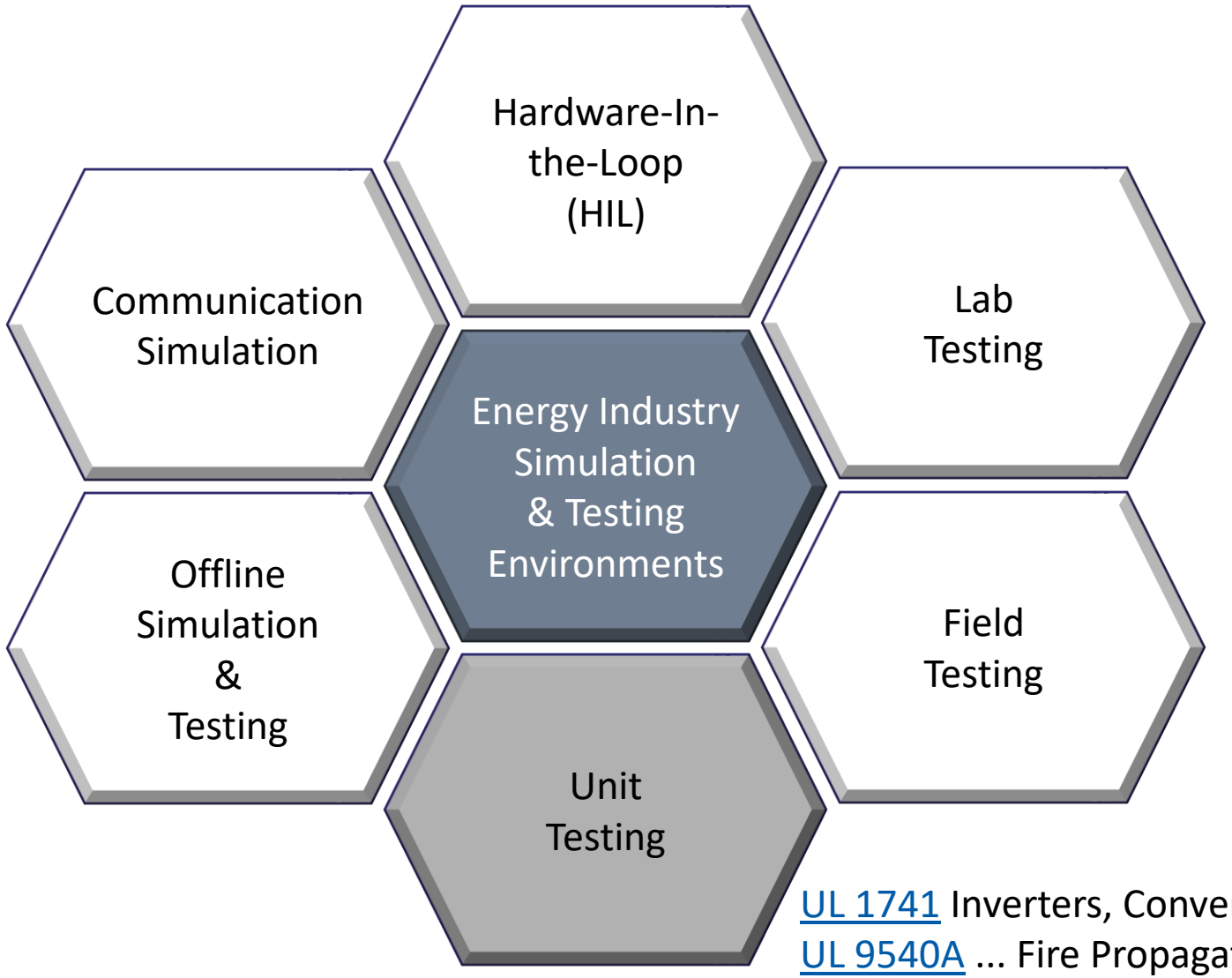
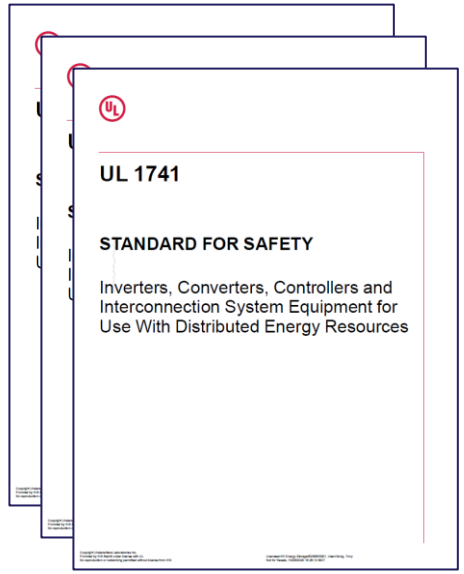
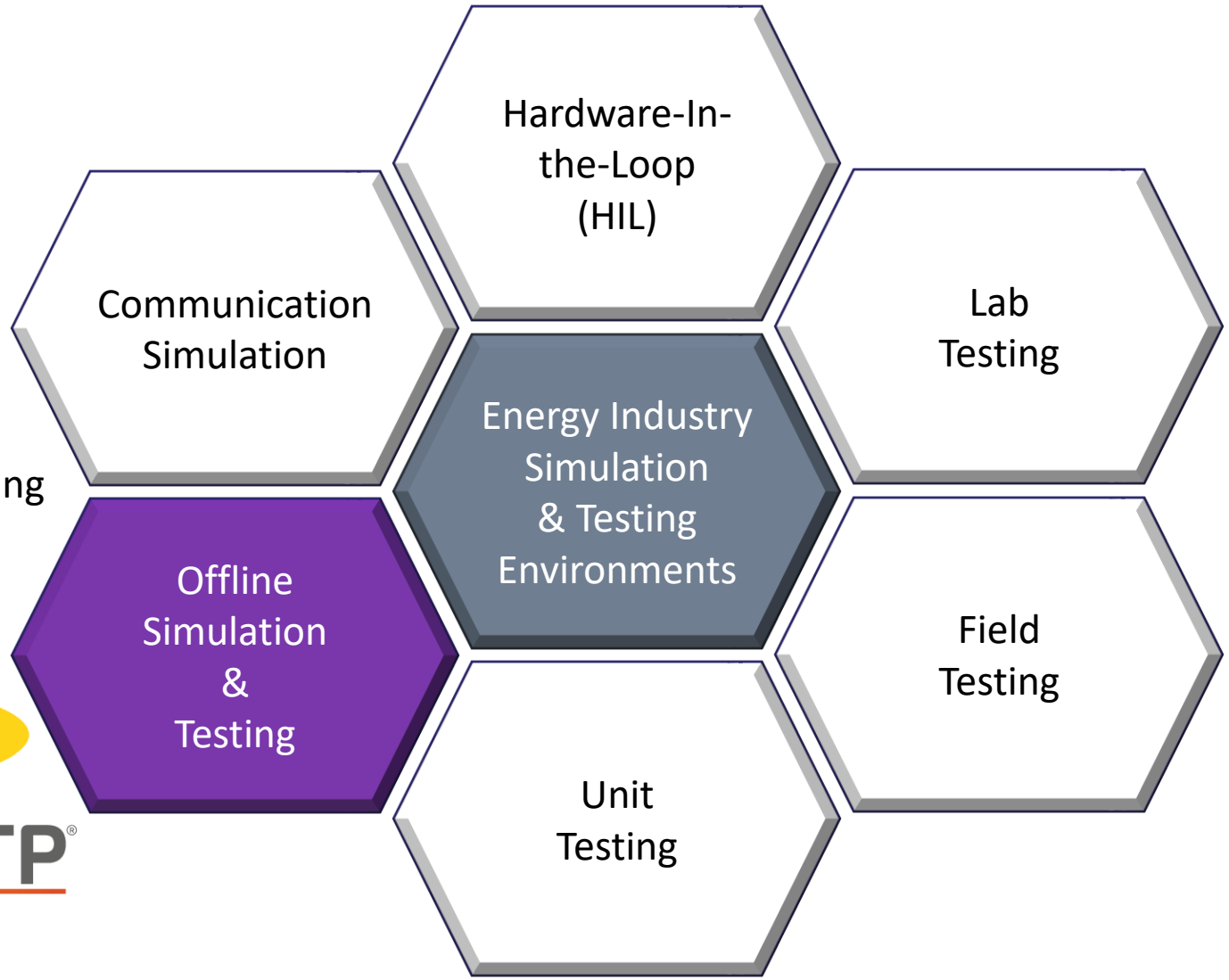






UL 1741 Inverters, Converters, …
UL 9540A … Fire Propagation in Battery ..



Electrical Performance Testing

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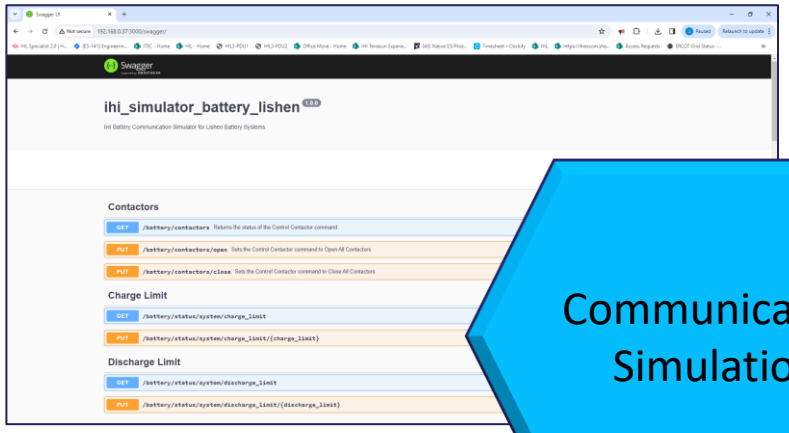
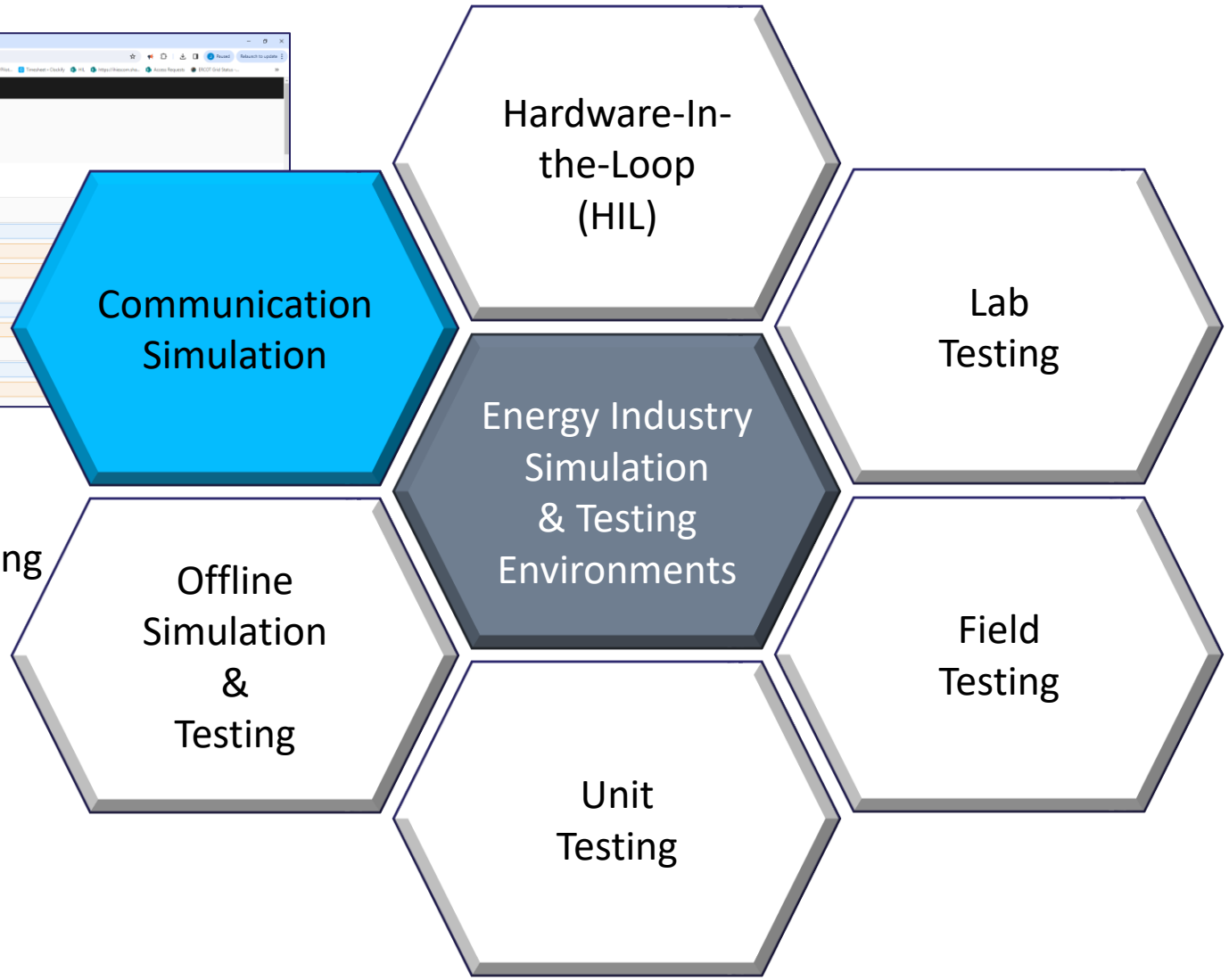
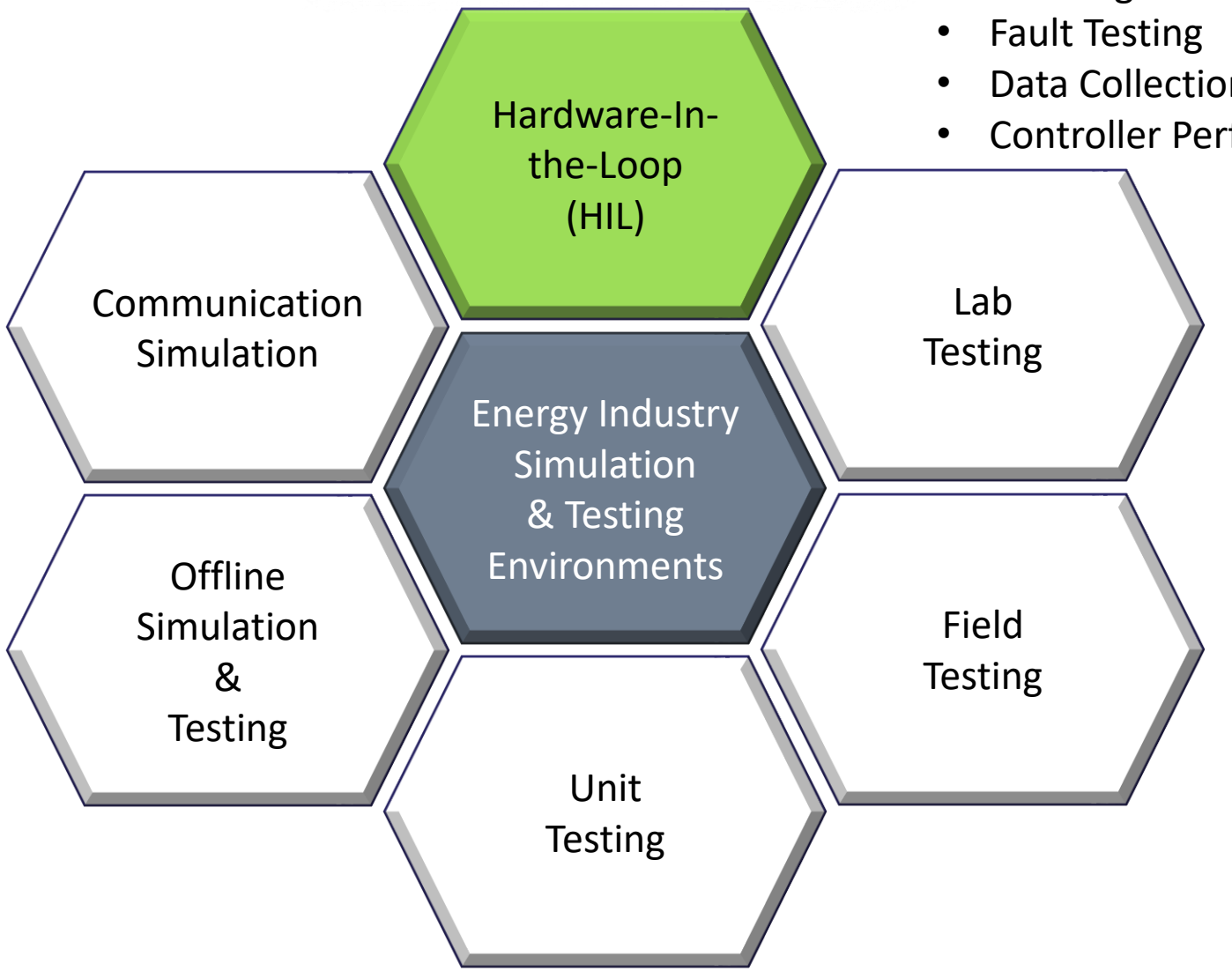
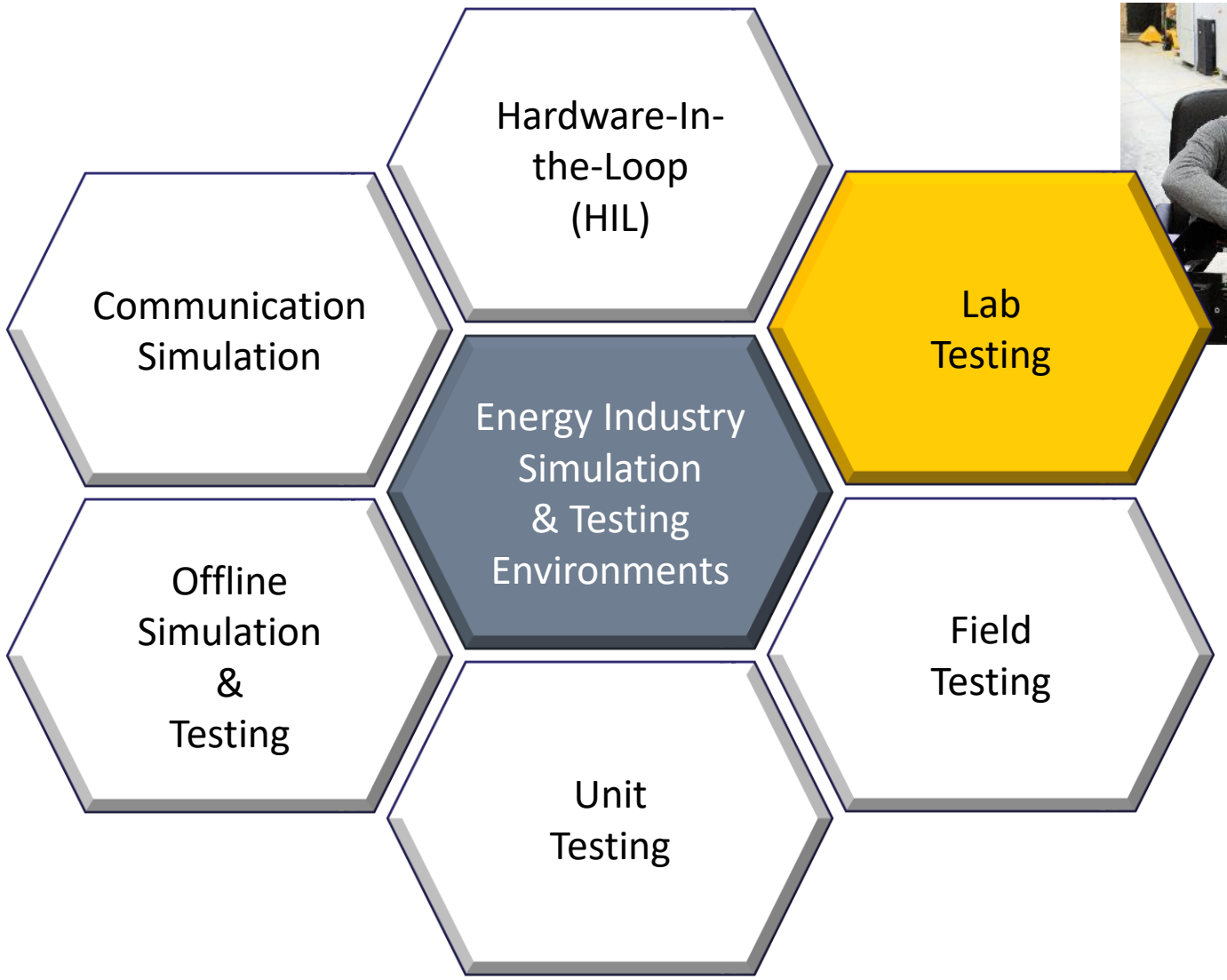


- Sequence Testing
- Status Testing
- Data Collection Testing
- Monitoring Testing
- Reporting Testing

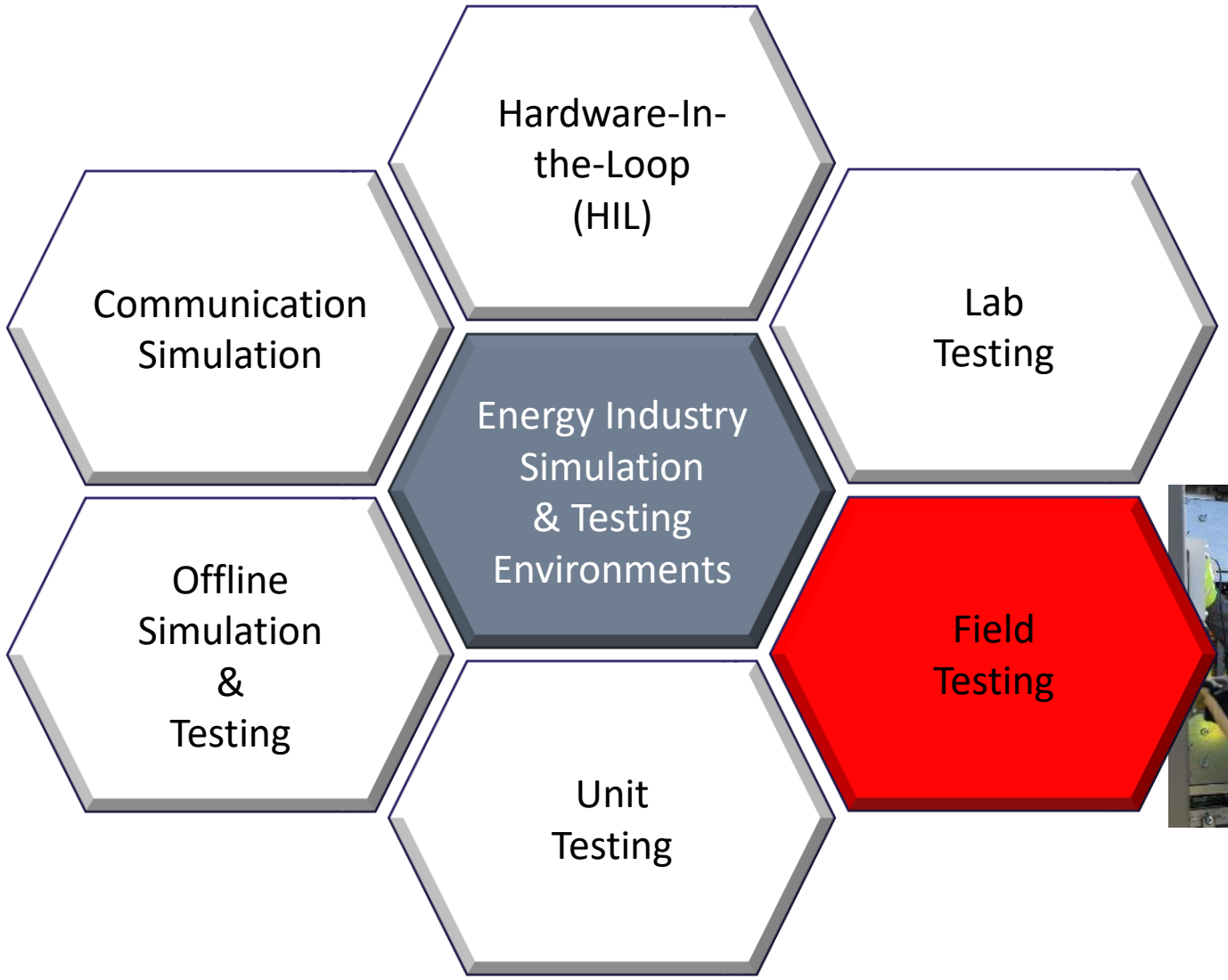


- Status Testing
- Operational Testing
- Warning Testing
- Fault Testing
- Data Collection Testing
- Controller Performance Testing

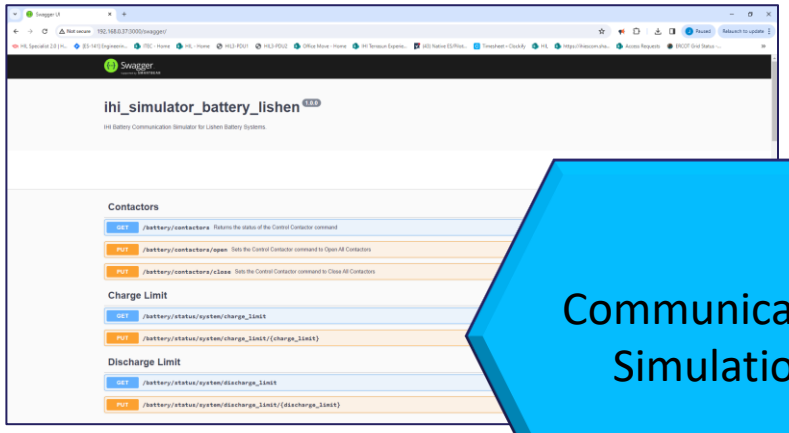




- Status Testing
- Warning Testing
- Fault Testing
- Operational Testing
- Electrical Performance Testing
- Data Collection Testing
- Monitoring Testing



- Operational Testing
- Warning Testing
- Fault Testing
- Electrical Performance Testing
- Data Collection Testing
- Monitoring Testing
- Reporting Testing



Hardware-In-the-Loop (HIL)

Communication Simulation

Lab Testing

Energy Industry Simulation & Testing Environments

Offline Simulation & Testing

Field Testing

Unit Testing

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UL 1741 Inverters, Converters, …

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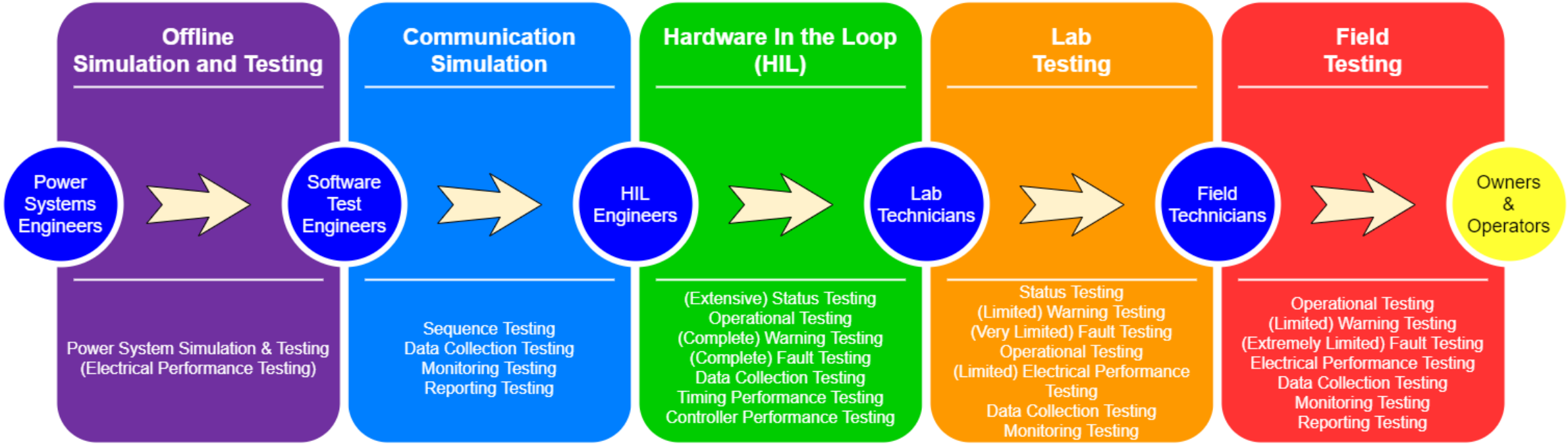
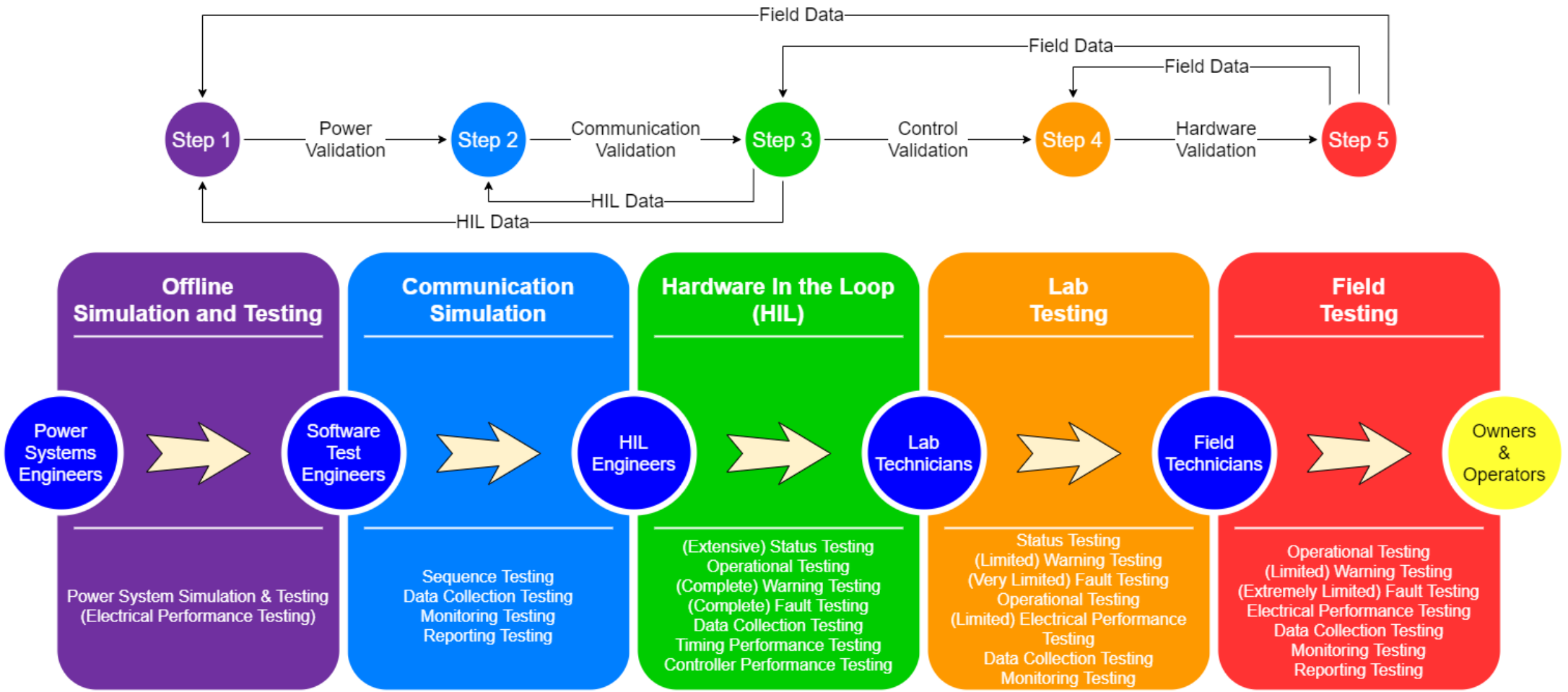
Integration Simulation and Testing Steps



Integration Simulation and Testing Flow



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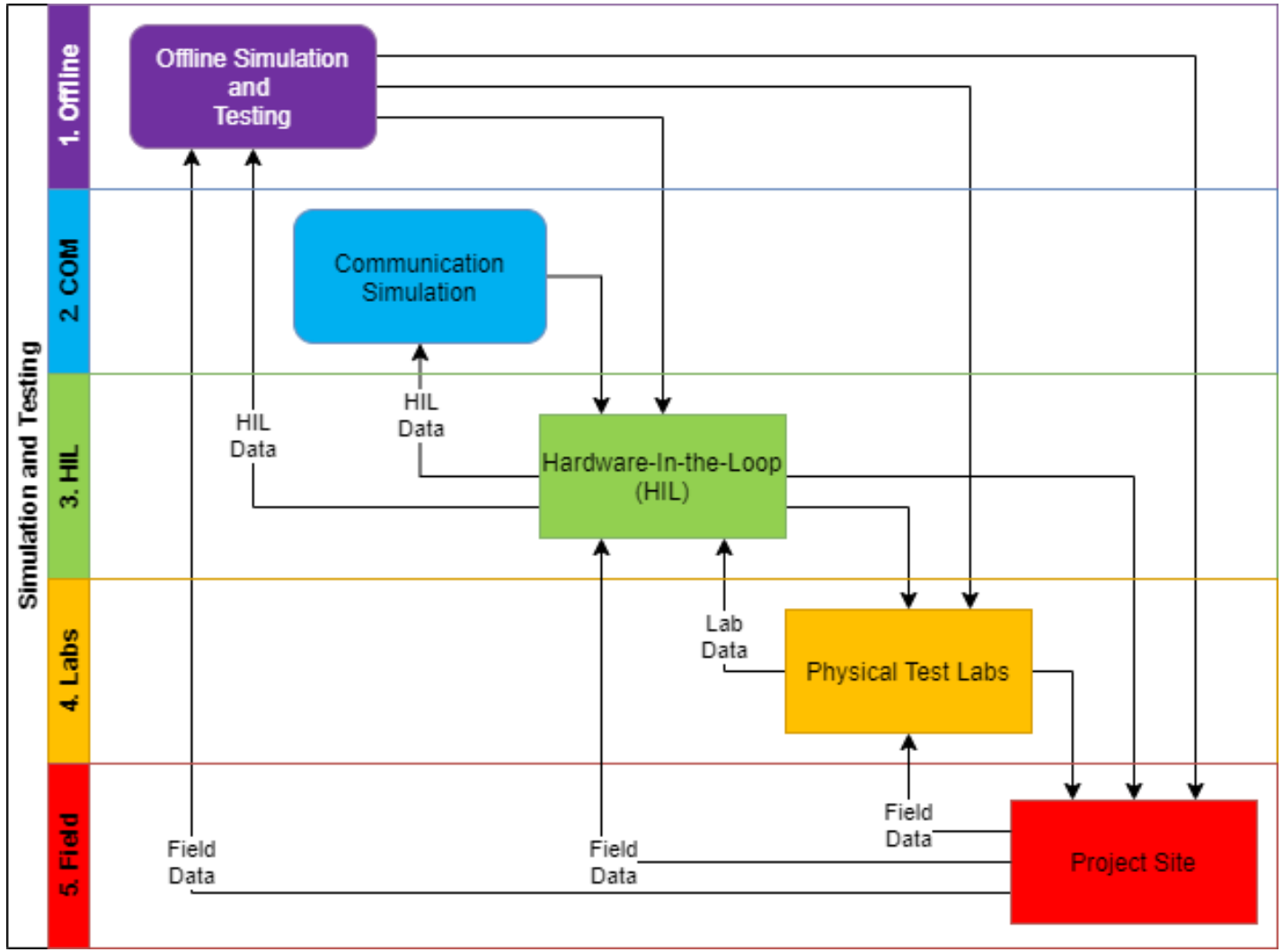
Integration Simulation and Testing Chart



Simulation and Test Comparisons

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Category	Pros	Cons	Cost	Availability	Flexibility	Safety	Accuracy
1. Offline	1.1 Extremely safe with only simulated electrical transfers	1.1 May NOT match the actual behavior of the real system 1.2 Simulation Resources may be expensive 1.3 Simulation time may be significant	$$	Medium	Extremely High	Extremely Safe	Low
2 COM	2.1 Extremely safe with only simulated electrical transfers 2.2 Can easily scale very large systems 2.3 Easy to share and deploy 2.4 Can be used by many people and teams simultaneously	2.1 May NOT match the actual behavior of the real system 2.2 Does NOT allow for accurate timing testing 2.3 Does NOT allow for accurate performance testing	$	Extremely High	Extremely High	Extremely Safe	Extremely Low
3. HIL	3.1 Extremely safe with only simulated electrical transfers 3.2 Can be used for controller timing/performance testing 3.3 Can simulate most (if not ALL) Warnings and Faults 3.4 Relatively easy to automate tests 3.5 Tests can be re-run very quickly 3.6 Extremely safe as no Real (P) or Reactive (Q) is used 3.7 Modular (Component-level testing and isolation)	3.1 May NOT match the actual behavior of the real system 3.2 Can really only be used by one person at a time 3.2 Does NOT scale to very large systems 3.4 Modules must be manually reconfigured	$$	Medium	High	Safe	Low
4. Labs	4.1 Provides true behavior of small systems 4.2 Can be used for controller timing and performance testing 4.3 Can be used for electrical timing and performance testing	4.1 Does NOT scale easily 4.2 Can really only be used by one person at a time 4.3 Can only test small number of warnings/faults 4.4 Almost all components must be used for every test 4.5 Tests often take more time than simulations 4.6 Can be dangerous as real electricity is used 4.7 Can be expensive as real electricity is used 4.8 System often can't be tested at Nameplate	$$$	Low	Low	Dangerous	Medium
5. Field	5.1 True system behavior 5.2 True timing and performance 5.3 System can be tested at Nameplate and/or true configuration	5.1 Explicitit permission to test is required 5.2 Can really only be used by one person at a time 5.3 Very small number of warnings\faults tests allowed 5.4 Tests often take more time than simulations 5.5 Can be dangerous as significant electricity is used 5.6 Can be expensive as significant electricity is used	$$$$	Extremely Low	Extremely Low	Extremely Dangerous	Extremely High

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Hardware-In-the-Loop (HIL) Summary

HIL systems are the best places to simulate faults and warnings, which will **protect real equipment**

HIL systems **save people** from getting hurt while learning about and working with Energy Systems and Devices

HIL systems can simulate electrical transfers using real controller hardware to **save time and money**

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