SAND2022-14889C

U.S. DEPARTMENT OF ENERGY

UNIFI is co-led by NREL, University of Washington, and EPRI

unifi consortium

universal interoperability for grid-forming inverters

Integration and Validation

Organization

unifi consortium

Leadership

Establish management & governance structure to support sustained US leadership in GFM tech

Develop/Update Interoperability Guidelines and Functional Requirements

Thrusts

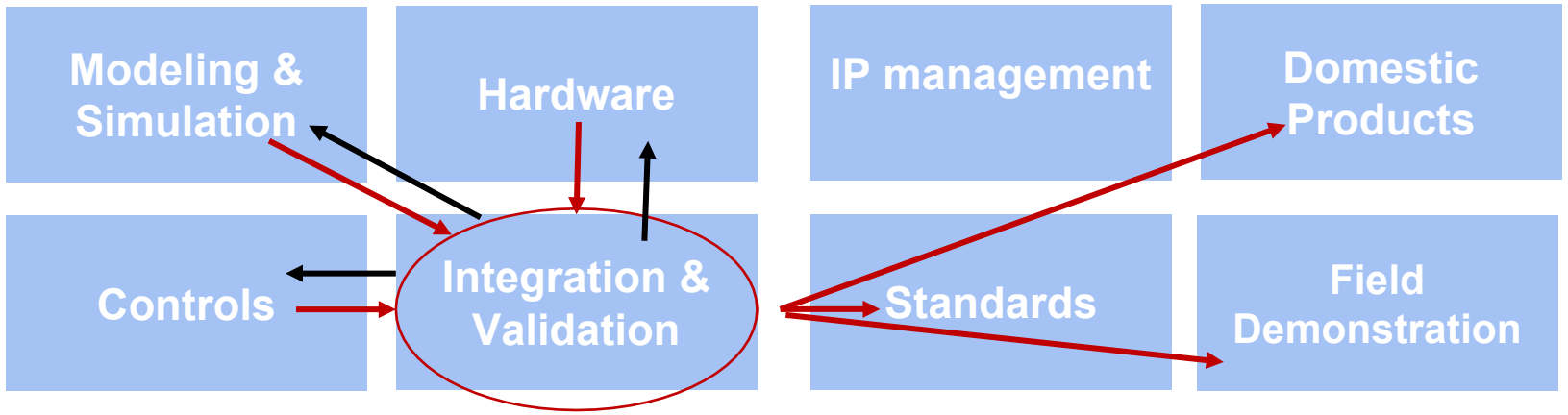
Research & Development

- Advance R&D for GFM technologies
- Ensure a coherent & comprehensive portfolio of solution sets
- Integrate & evaluate new capabilities, products, & processes

Demos & Commercialization

- Provide guidance & transition R&D to commercial products and applications
- Demonstrate solutions that showcase multi-vendor interoperability
- Bring together public+private entities

Areas



R&D (Mod/Sim, Controls, Hardware)

- Proof of concept development
- Application of new ideas in simplified systems
- Can be simulated, HIL, or hardware, but limited and size and scope of aggregations/heterogeneity of technologies

I&V

- Evaluation of heterogeneous systems
- Interactions between assets in realistic power systems (e.g. with rotating machines, protection systems)
- Evaluation of R&D work product in reference systems
- Benchmarking of current technologies
- Evaluation of Interoperability Guidelines

D&C (Field Demo, Standards)

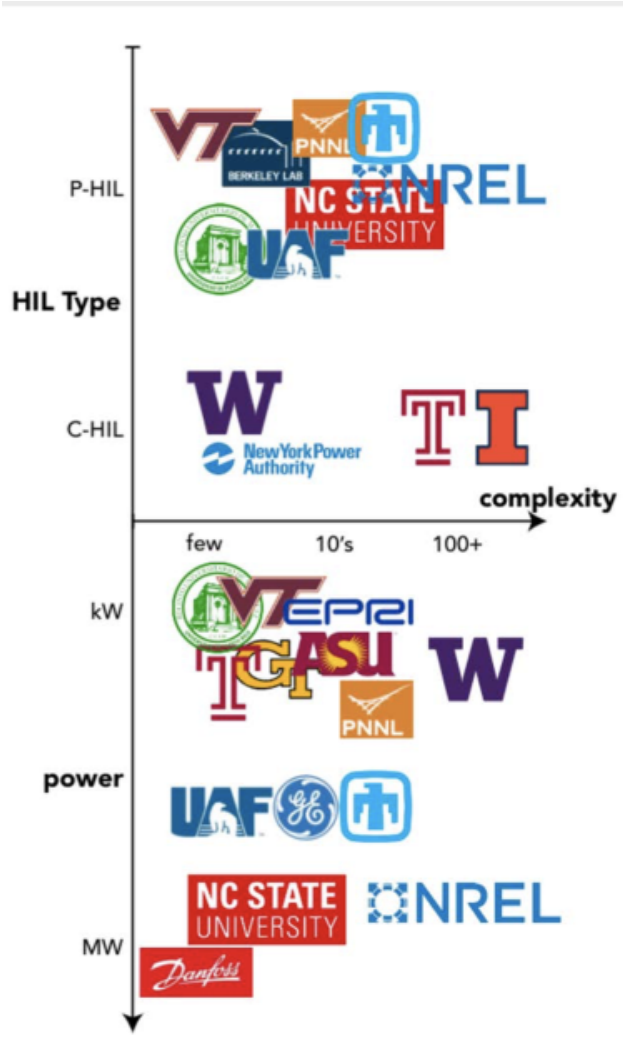
- Real application of field ready technology focused on actual systems
- Full complexity of aggregation/heterogeneity

Integration and Validation -- Focus

1. **Evaluate** performance of GFM technologies in **representative** integrated power system environments
   - Highly heterogeneous systems, e.g., control schemes, resources
   - Benchmark proposed R&D technology against commercially available counterparts
   - Validate models and hardware in complex systems

2. Establish a **conduit** between the R&D areas to activities that are a part of the D&C Areas
   - Develop characterization procedures for single units, aggregations of units, and heterogeneous systems

3. Evaluate the Consortium developed ***Interoperability Guidelines & Functional Requirements***



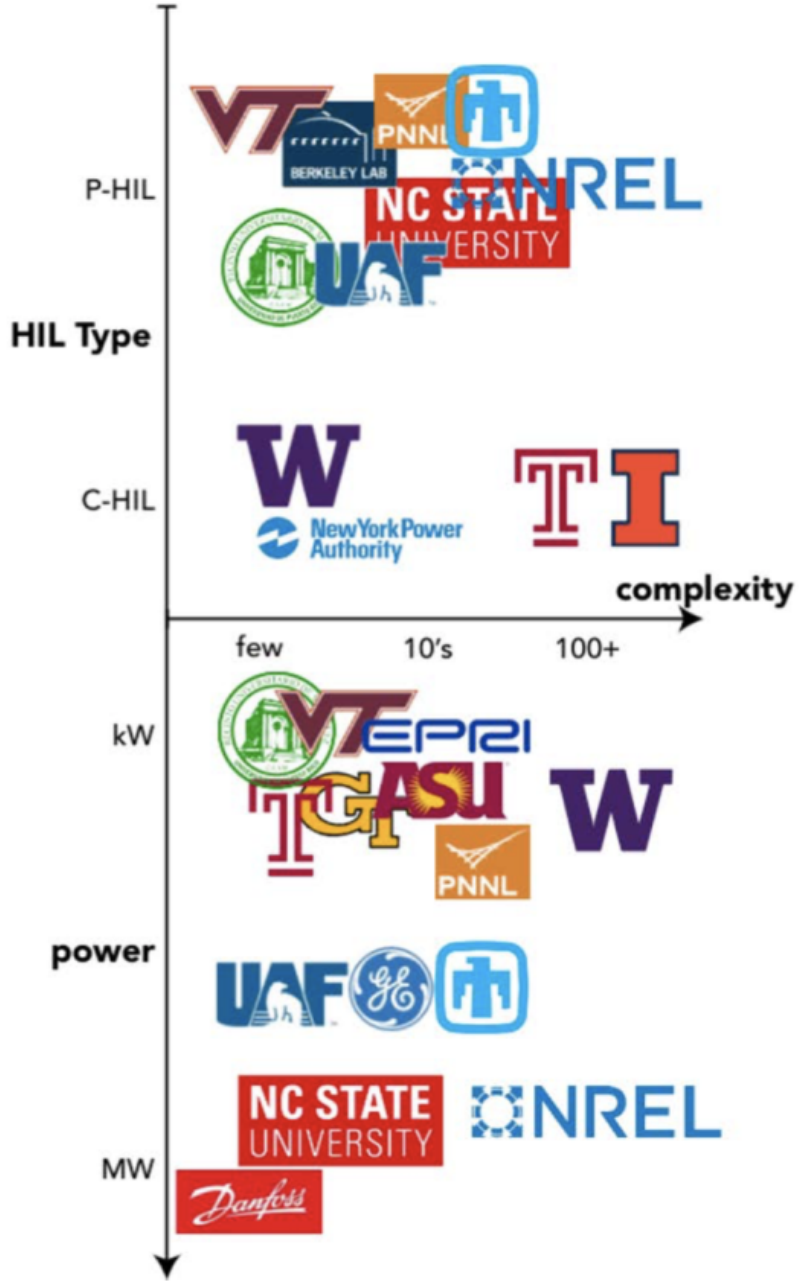
Integration and Validation -- Focus

Work is roughly split into three Areas:

1. UNIFI validation infrastructure and IBR baseline characterization
   - Developing experimental capabilities/systems for measuring GFM in systems
   - Baselining current capabilities of GFM

2. Integration of GFM IBRs into Power Systems
   - Evaluating R&D work product and quantifying improvements over baseline

3. 1+MW Multi-vendor Experiments
   - Hardware demonstration for heterogeneous systems



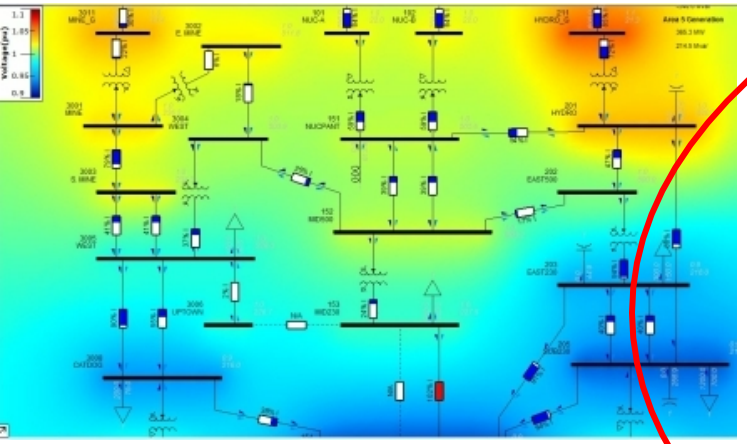
Task 1: Validation infrastructure and IBR baseline characterization

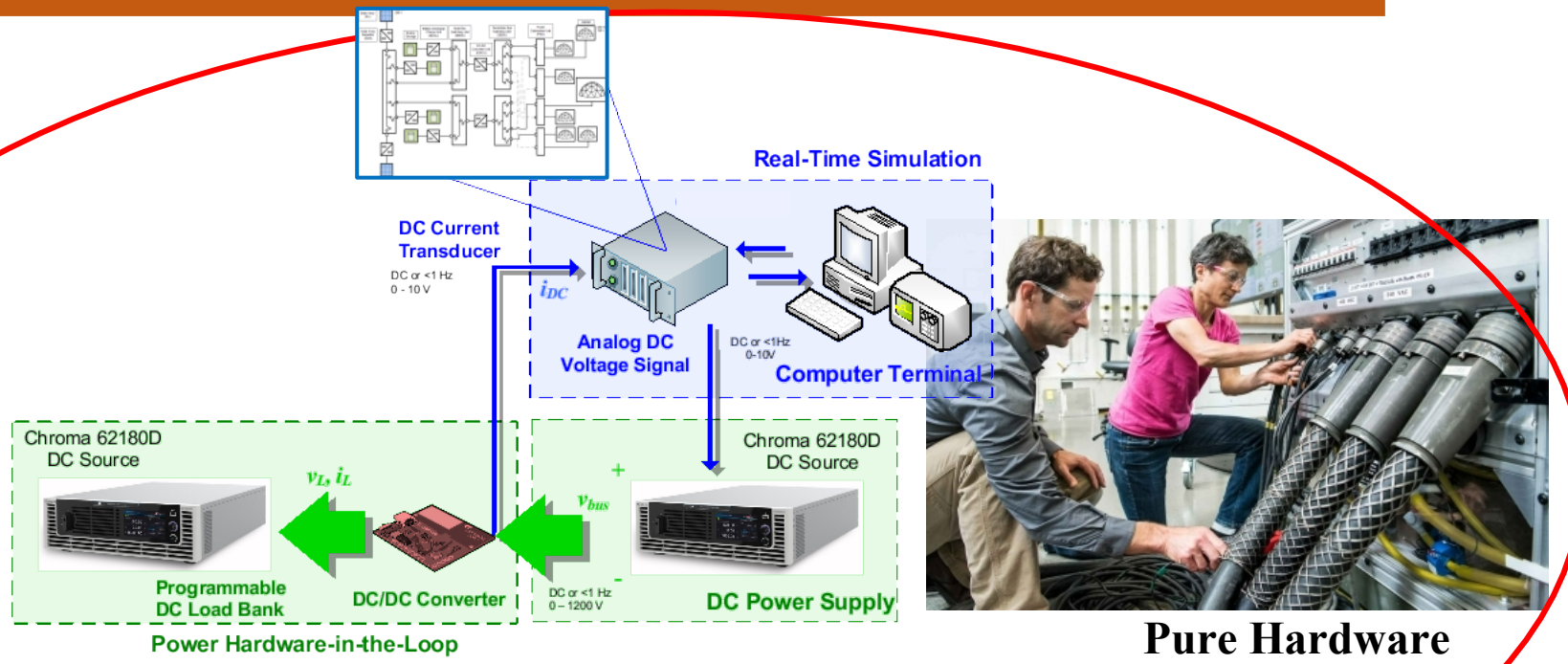
- **Development of validation and verification** (V&V) infrastructure across partner's facilities
  - Initial setup, commissioning and documentation of testbeds

- Baseline characterization of selected commercial off-the-shelf (COTS) IBRs
  - Use results to complement and inform activities of the modeling, controls and hardware areas

Integration and Validation – Tools for heterogeneous systems

Flexibility & Scalability





Pure Simulation

Extended system representation

Controller HIL

High fidelity control systems

Power HIL

High fidelity Unit Response

Pure Hardware

Nonlinear interactions

Fidelity

CHIL, PHIL, and Hardware evaluation of GFM in systems:

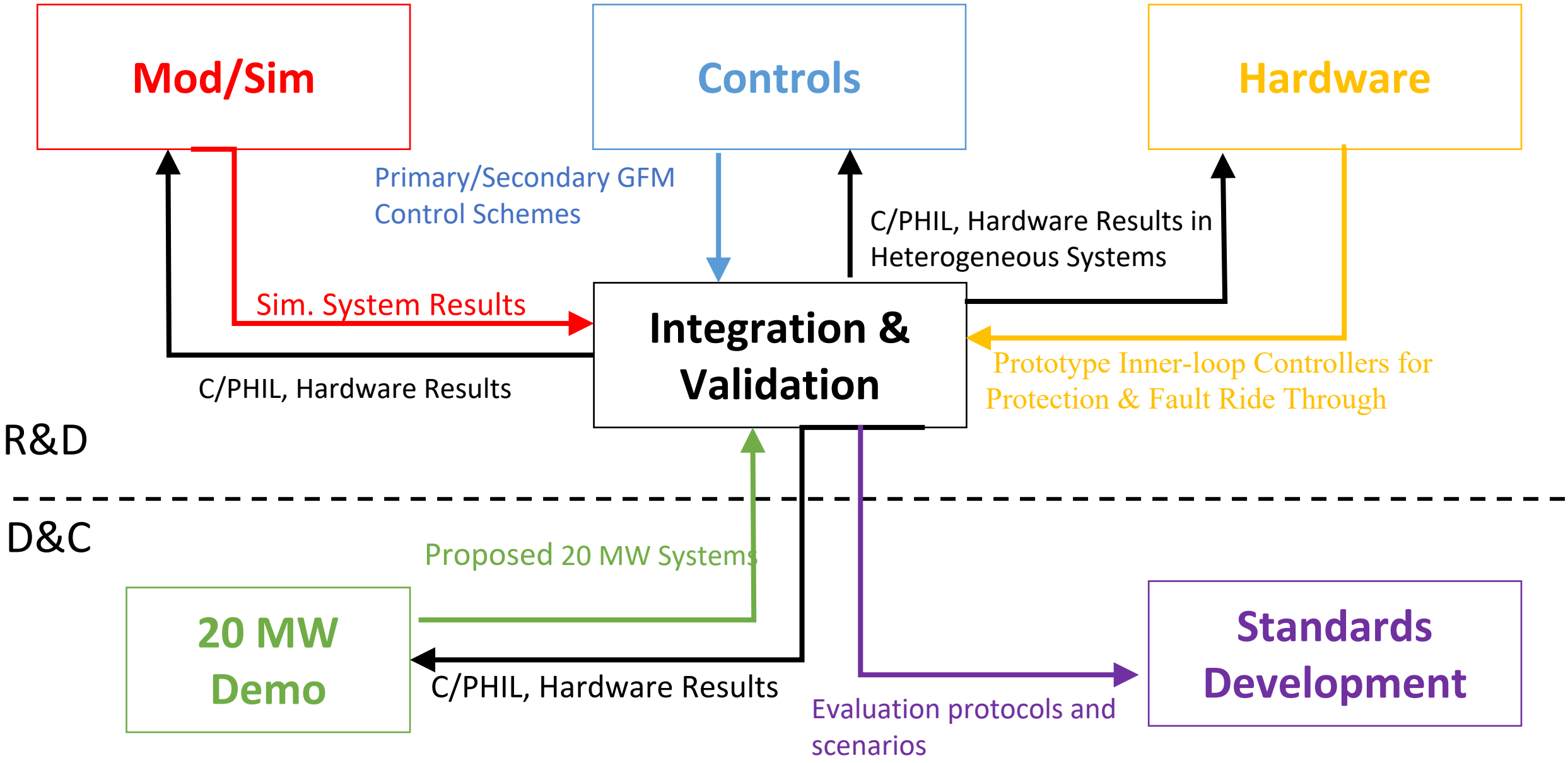
- Mixtures of GFM, GFL, rotating machines
- Normal operating conditions
- Contingency conditions (fault, blackstart)

Task 2: Integration of GFM into Power Systems

- Development and refinement of testing protocols and scenarios for UNIFI Interoperability Guidelines and Functional Requirements
  - Criteria for evaluating single units, aggregations of units, and heterogeneous systems
  - Specifications necessary for GFM IBRs to ensure seamless interoperability with the power system

- Application of testing protocols against GFM models and hardware/control prototypes produced by the other R&D Areas, or provided by industry partners
  - Quantify the impact of GFM behavior in heterogenous systems
  - Consider both normal and contingency conditions over all time-scales
  - Evaluate Consortium proposed interoperability behaviors
  - Evaluate R&D products from across the Consortium

Integration and Validation -- Focus



Task 3: 1MW Hardware Demo

1 MW Experiment – at NREL in Year 3

- Includes various physical sizes (250W-1MW)
- Three-phase, single-phase generation & loads
  - GFM, GFL, & synchronous machines
  - Comms interfaces (2030.5, SunSpec)
- Multiple source-side resources (PV, energy storage, wind (if possible))
- Coupled to PHIL to evaluate scales: 1MW microgrid to larger grids
- 50%, 75%, 90%, and 100% power contribution from GFM IBRs
- Network connections (LV and MV, overhead and conductors)
- Explore options to distribute demonstration amongst capabilities in multiple partner labs (ex. Via Real Time Simulation)
- Illustrate the *Interoperability Guidelines* at work with multiple vendors and wide variety of functionalities

Integration and Validation – Milestones

Year	Validation infrastructure and baseline characterization	Integration of GFM IBRs into Power Systems	1+ MW Demo
1	• Standardize information formats and testing architecture and use cases for C-HIL and P-HIL across Consortium • Identify set of baseline GFM inverters and their capabilities for laboratory testing	• Draft of evaluation protocols for GFM that incorporates expected behavior for single GFM units, GFM aggregations, and hybrid systems	• Specify requirements for 1+MW assets and scenarios
2	• Commission C-HIL, P-HIL, and hardware setups for use cases from BP1	• Utilize setups use cases to evaluate baseline GFM operations and proposed envelope of GFM functional behaviors for contingency scenarios	• Commission 1+MW demonstration in laboratory

Integration and Validation – Milestones

Year	Validation infrastructure and baseline characterization	Integration of GFM IBRs into Power Systems	1+ MW Demo
3	• Detailed evaluation of candidate 20+MW demo components(s) under normal and contingency operation.	• Incorporate and evaluate GFM control models with communication interfaces in real-time CHIL • Validate GFM control models and protection coordination under symmetrical/asymmetrical faults and system restoration in HIL	• Conduct 1MW scenarios as determined in BP1.
4	• Demonstrate user-facility experimental workflow with project partners	• Evaluate resynchronization and fault current behavior (both balanced and unbalanced) over all relevant timescales in use cases • Validate GFM models against laboratory tests of GFM inverters	• Complete report on 1+MW demonstration system evaluation
5	• Final Report for proposed interoperability requirements and testing protocols as evaluated in C-HIL and P-HIL setups	• Evaluate designed secondary control diagram with usage cases in contingency scenarios.	

Integration and Validation – Milestones

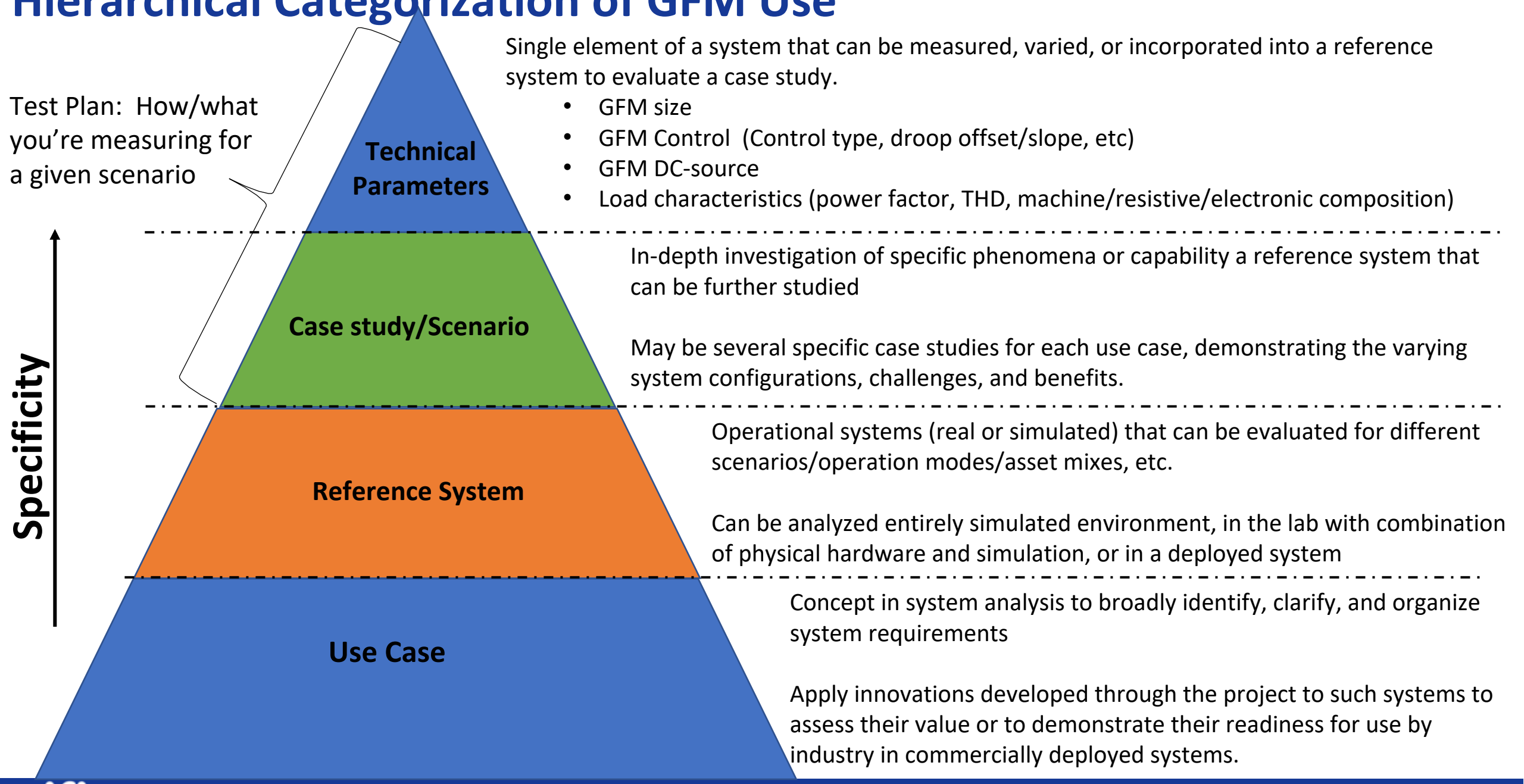
Year	Validation infrastructure and baseline characterization
1	• Standardize information formats and testing architecture and use cases for C-HIL and P-HIL across Consortium

Establish common use cases, scenarios, and references systems for GFM integration

- Standardized systems and test cases across the multiple R&D areas
- Definition of operational benchmarks
- Evaluate baseline (current state-of-the-art) GFM operation and future R&D work produc
- Understand unit-level and system-level performance for different technologies.

I&V group has developed a hierarchical categorization for GFM testing

Hierarchical Categorization of GFM Use



Test Plan: How/what you're measuring for a given scenario

Single element of a system that can be measured, varied, or incorporated into a reference system to evaluate a case study.

- GFM size
- GFM Control (Control type, droop offset/slope, etc)
- GFM DC-source
- Load characteristics (power factor, THD, machine/resistive/electronic composition)

In-depth investigation of specific phenomena or capability a reference system that can be further studied

May be several specific case studies for each use case, demonstrating the varying system configurations, challenges, and benefits.

Operational systems (real or simulated) that can be evaluated for different scenarios/operation modes/asset mixes, etc.

Can be analyzed entirely simulated environment, in the lab with combination of physical hardware and simulation, or in a deployed system

Concept in system analysis to broadly identify, clarify, and organize system requirements

Apply innovations developed through the project to such systems to assess their value or to demonstrate their readiness for use by industry in commercially deployed systems.

Hierarchical Categorization of GFM Use

Use Cases	Microgrid----	Island (isolated) Grid	Distribution Connected	Transmission connected
Reference Systems (linked to mod/sim software library)	• Banshee • Sheriff • Consortium for Electric Reliability Technology Solutions (CERTS) • 1MW Demo System	• Hawaiian Islands (Oahu, Kauai, Maui) • St. Mary's, AK • South Australia, AEMO • Culebra, PR	• IEEE test feeders (342-Node, 13-Node, 34-Node, 123-Node, 8500 system) • EPRI Ckt 5 • 20 MW Demo	• 1WECC System • IEEE systems (39 Bus, 14 Bus) • 2000 Bus Synthetic Texas System • Hydro Quebec System • Eastern Interconnect
Scenarios (linked to *Interoperability Guidelines and Functional Requirements*)	• Blackstart • Generation Loss/Load step • Fault (balance/unbalance) • Phase Imbalance (voltage/power) • Island/resynch. (control/uncontrolled) • Inductive Inrush/motor stall • Overload (load > generation) • DC-side Dynamics	• Blackstart • Generation Loss/Load step • Fault (balanced/unbalanced) • Phase Imbalance (voltage/power) • Multi-segment island/resynch • Overload (load > generation) • Inductive Inrush/motor stall • DC-side Dynamics	• Generation Loss/Load Step • Fault (distribution) • Phase Imbalance(voltage/power) • Loss of Utility • DC-side loss of generation • Inductive Inrush • Protection Coordination • Overload (load > generation) • Fault (Transmission)	• Generation Loss/Load Step • Fault (Distribution) • Blackstart • System oscillation/transient stability • Line Series Compensation • FACTs device interaction • Fault (Transmission) • Protection Coordination

1. **Bulk List** of Use Cases/Reference Systems/Scenarios

2. Rank based on importance from UNIFI input

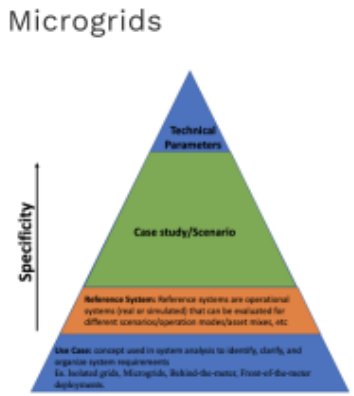
3. **Prioritize** Experimental setups considering importance ranking and organizational capabilities

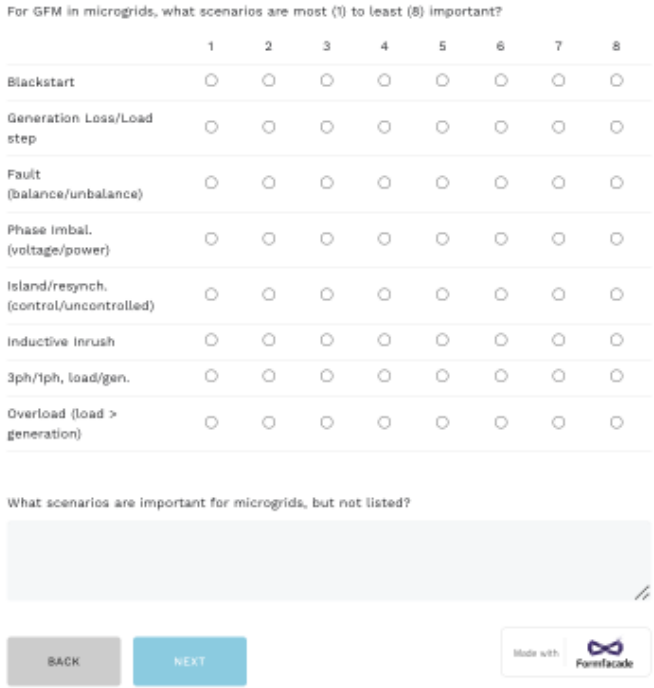
4. **Feedback** from other Working Groups and Stakeholders

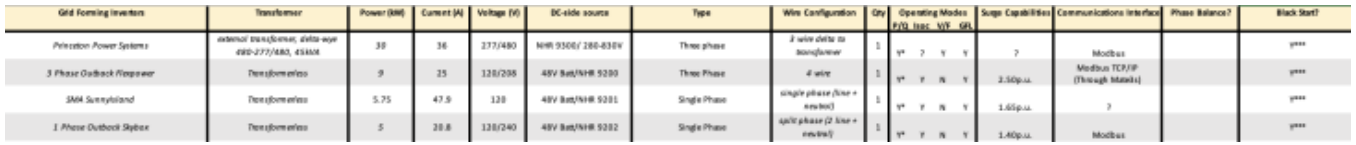
Finalize

5. Use Cases, etc.
6. Organizational capabilities and assets
7. Partition scenarios (reference systems) according to organizational capabilities

CY23: Commission Setups
Carry out Testing on baseline GFMs



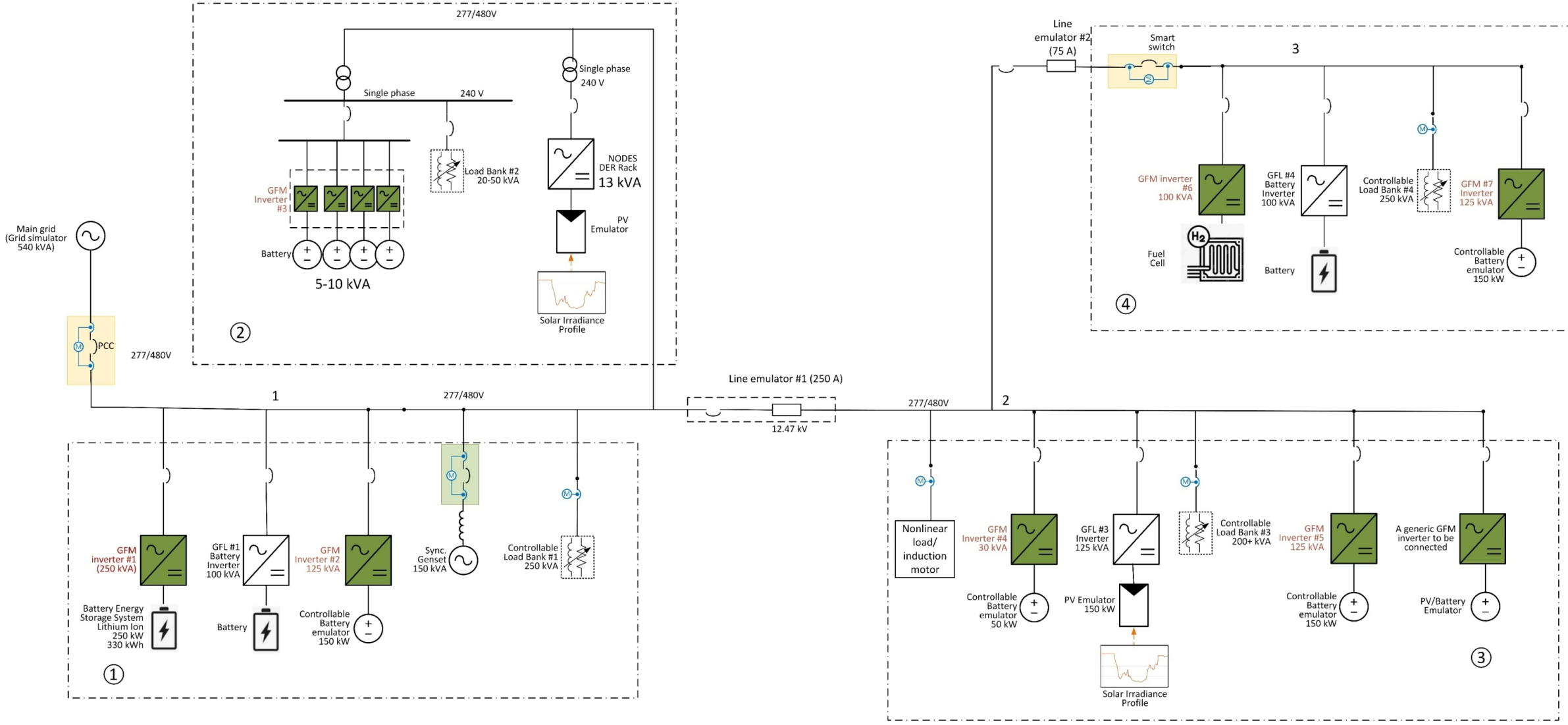




Integration and Validation – Milestones

Year	Integration of GFM IBRs into Power Systems	1+ MW Demo
1	• Draft of evaluation protocols for GFM that incorporates expected behavior for single GFM units, GFM aggregations, and hybrid systems	• Specify requirements for 1+MW assets and scenarios

Current work- 1MW Demonstration



7 GFM inverters 760 kVA
4 GFL inverters 340 kVA
1 synchronous Machine 150kW
5 controllable loads

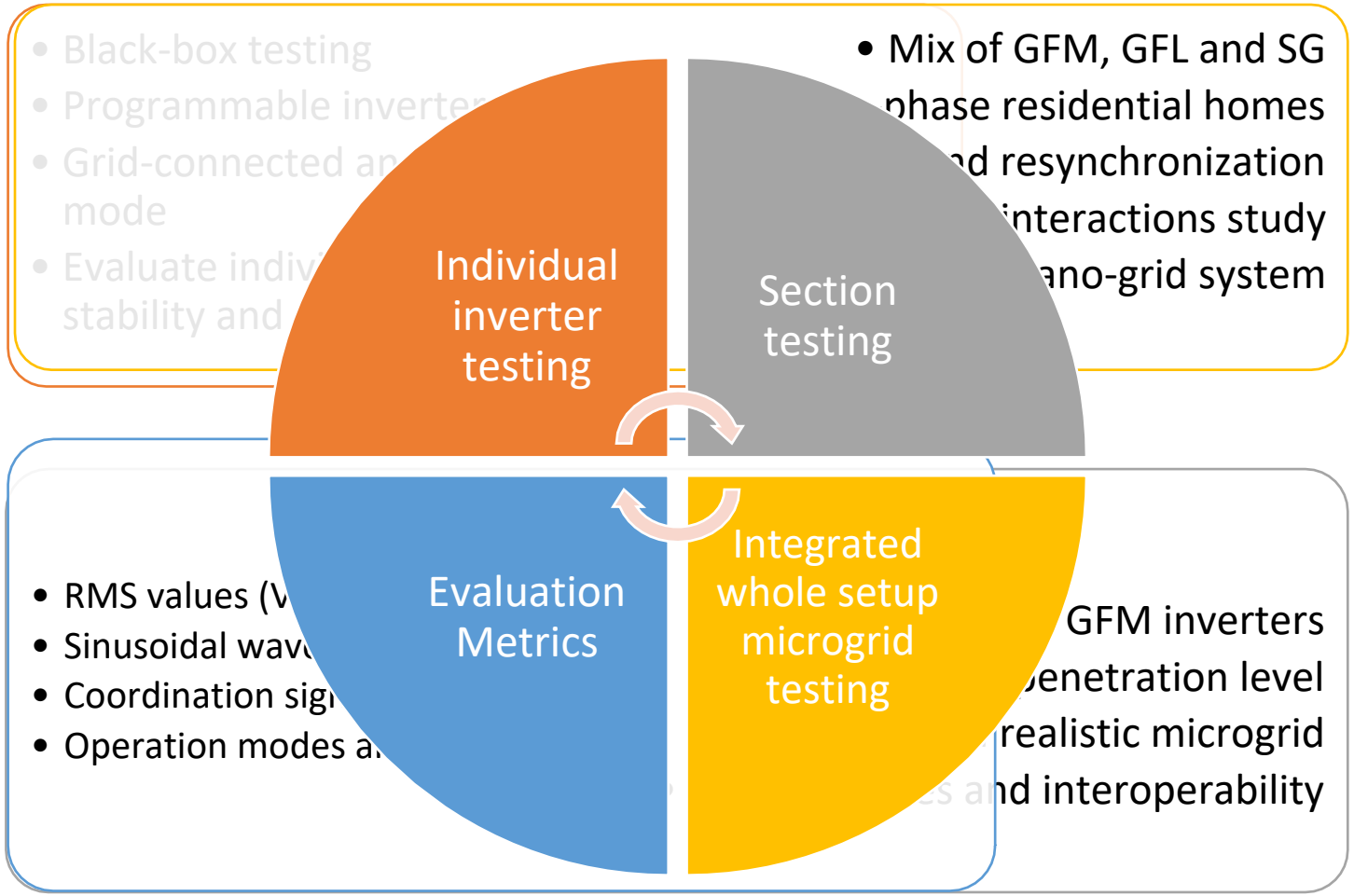
Preliminary Scheme for 1MW Demo

Component	Capacity	Controllability	Comms
Diesel generator	150 kVA	Droop coefficients, P* and Q*	Modbus TCP
GFM inverters (760 kVA in total)	125 kVA DynaPower (3 units)	Fully programmable	Modbus TCP
	5-10 kVA 1ϕ Enphase inverter	Can only change bias	2030.5-2018
	250 kVA EPC battery inverter	Can tune some control parameters	Modbus TCP
	30 kVA CE+T battery inverter	Can tune some control parameters	Modbus TCP
	100 kVA ABB battery inverter	Can tune some control parameters	Modbus TCP
GFL inverters (340 kVA) Note: we have 6 NODES DER racks. We just book one for now.	125 kVA SMA inverter	Receive external P and Q set points	Modbus TCP
	100 kVA DynaPower inverter (2 units)	Receive external P and Q set points	Modbus TCP
	13 kVA NODES DER rack (2 PV inverter, 1 battery inverter) (single-phase)	Receive external P and Q set points	Modbus TCP
Three phase loads (600 kVA)	250 kVA (2 units), 100 kVA	Can change PQ set point (spreadsheet)	Modbus TCP
Single-phase loads (40-100 kVA)	20-50 kVA (2 units)	Non-controllable	
Non-linear loads	100 kVA	Fully controllable power electronics to inject harmonics	
Motor load	200 kVA		

Preliminary Testing Capability for 1 MW demo

- Black start
- Loss of generation
- Phase unbalance
- Fault ride through
- Islanding (plan/unplanned) and reconnection
- Large inductive load
- GFL + GFM + rotating machine at various penetration
- Mix of three-phase and single-phase load
- Frequency regulation (secondary control)
- Voltage regulation (secondary control)
- Overload (individual GFM inverter)

Current work- Developing 1MW Demo Test Plan



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Thank you