# Clusters of Flexible PV-Wind-Storage Hybrid Generation (FlexPower)

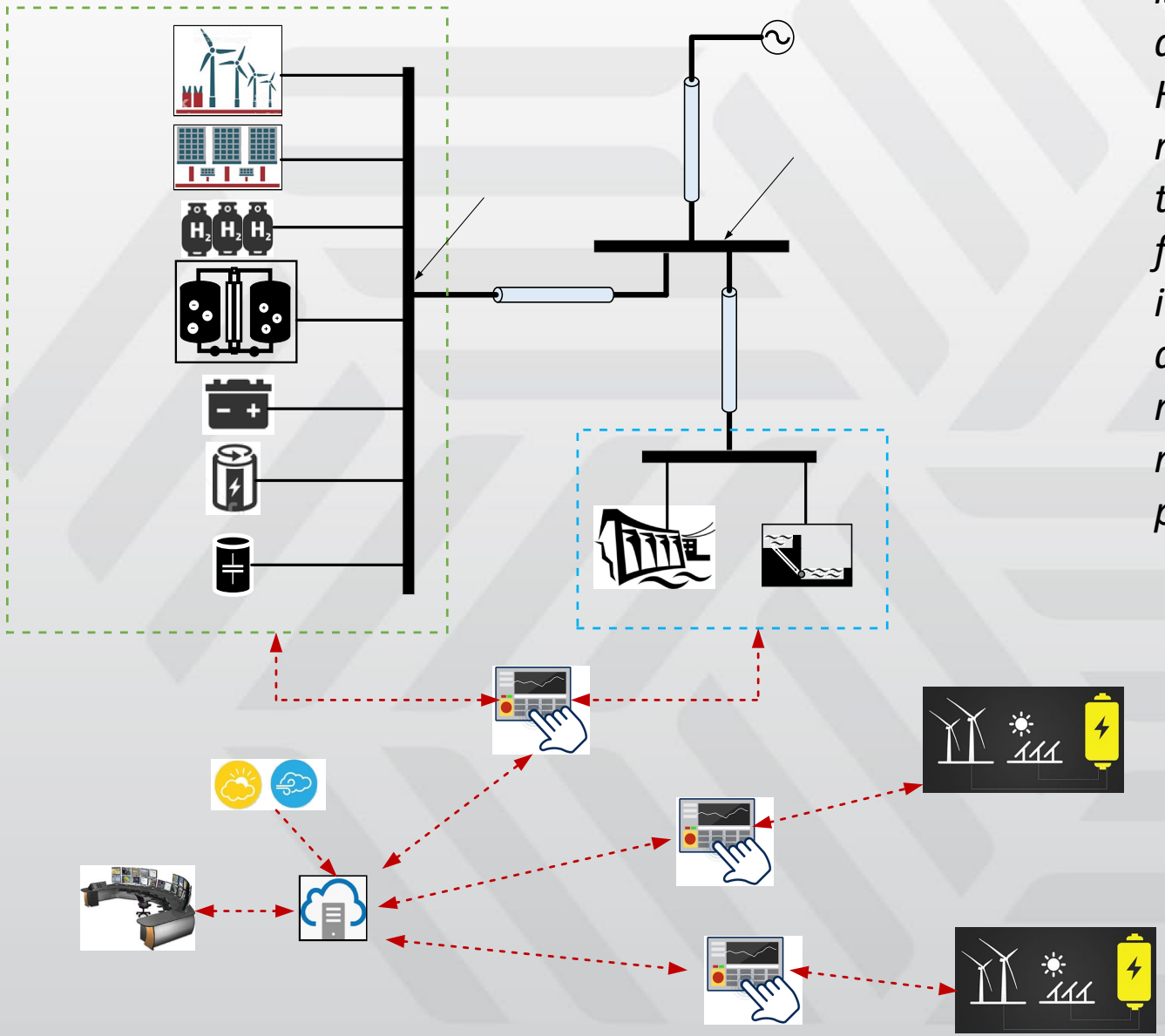
## Topic Area 6: Generation
### Subtopic 1: Hybrid Systems

Project Summary

NREL – INL - SNL project team

May 26, 2022

# General FlexPower Concept



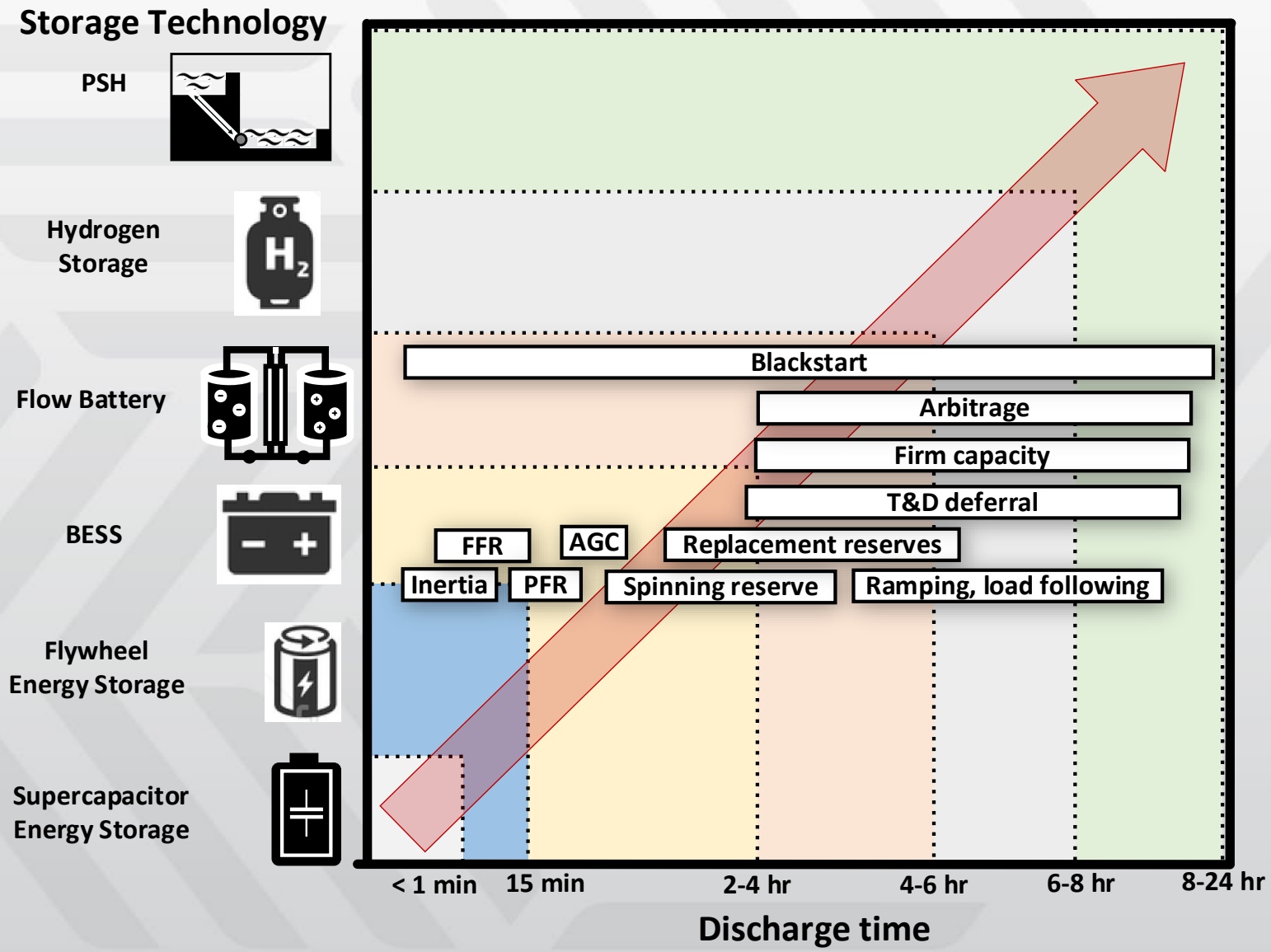
***The main research objective*** *of this project is to provide the industry with an answer and a solution to the following question: How can hybrid plants consisting of renewable energy and storage be transformed into fully dispatchable and flexible sources of energy suited to operate in day-ahead and real-time energy markets as well as flexibility and capacity services markets while providing all essential reliability and resiliency services to the bulk power system?*

Main tasks:

- Hybridization potential evaluation (wind, solar and hydro power/PSH
- Plant controls development and demonstration (wind, solar, hydro, storage)
  - PSH, H2 storage, BESS, kinetic, UCAP
  - Fast and slow controls
  - Resiliency services
- Regional integrations study

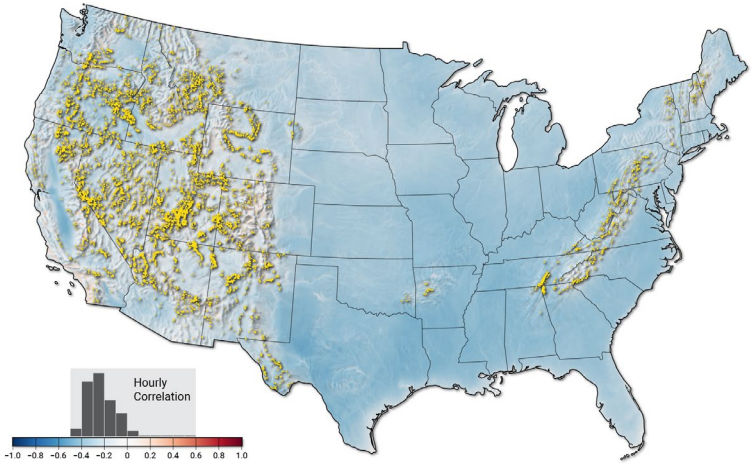
**Project team: NREL, INL, SNL**

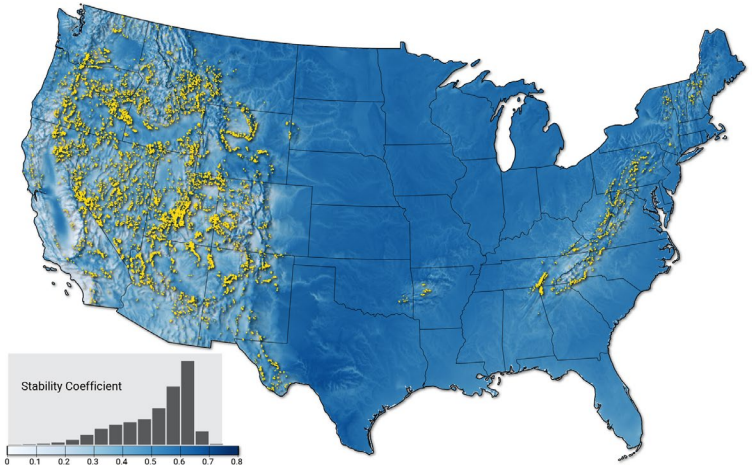
# Energy Storage in FlexPower

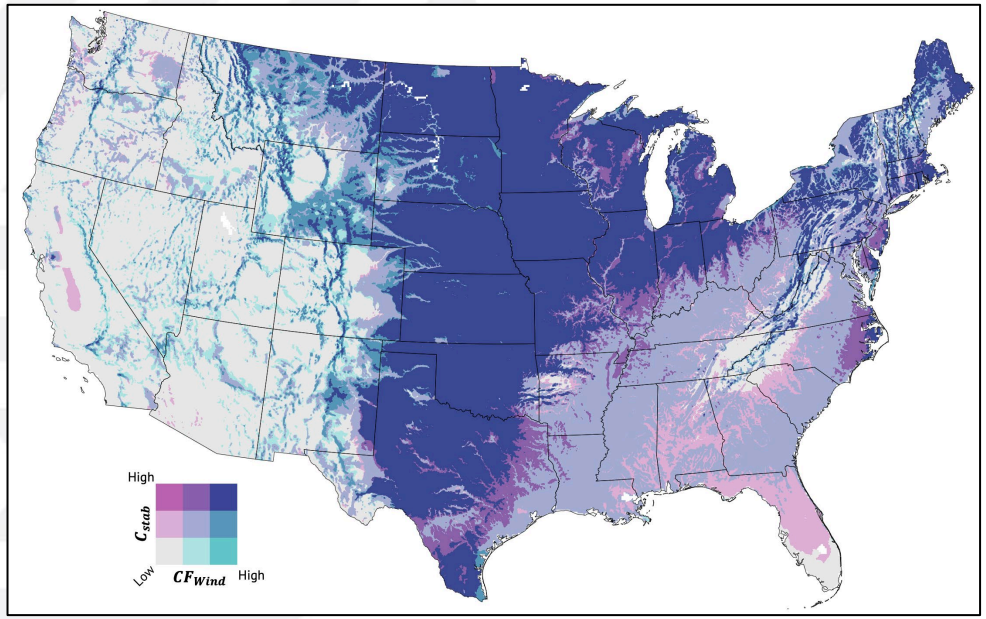


# Hybridization Potential Evaluation

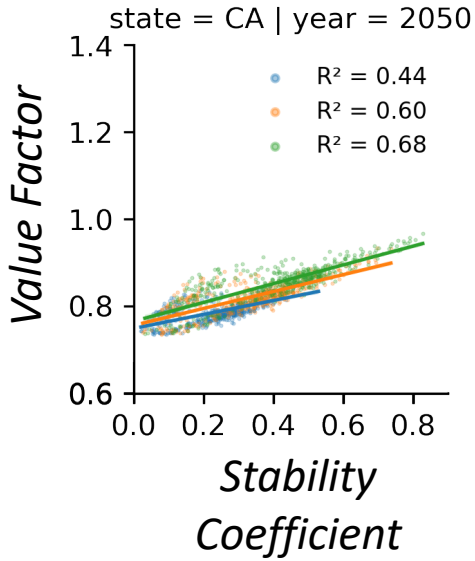
- Generated maps comparing complementarity with pumped storage hydropower resource assessment (top figures)
- Completed draft journal article covering wind-PV complementarity analysis, which:
  - **Wide range of metrics** for **wind-PV complementarity**, based on **hourly** generation profiles derived across multiple **weather years**
  - Price-taker analysis exploring the relationship between **complementarity and energy value**, now and in the future
  - Draft to WETO: end of Q2



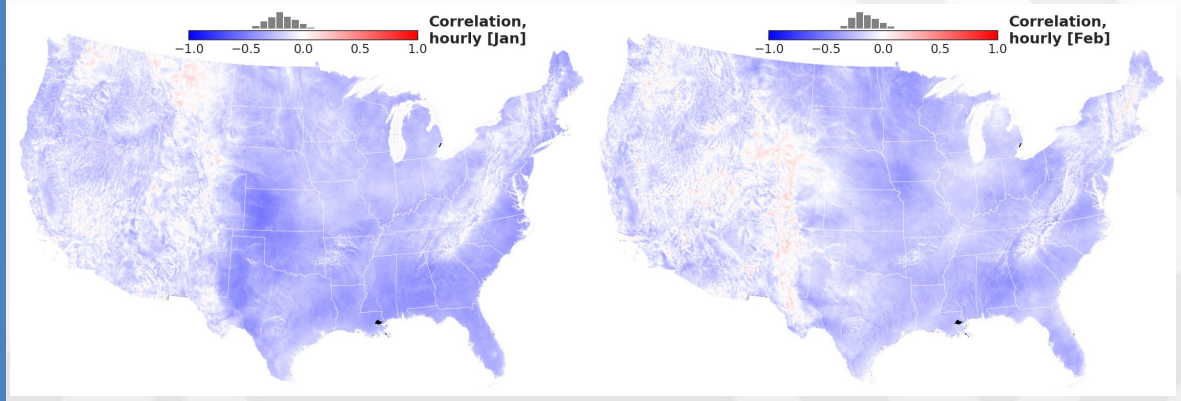




*Comparing wind capacity factor and stability benefits of hybridization*



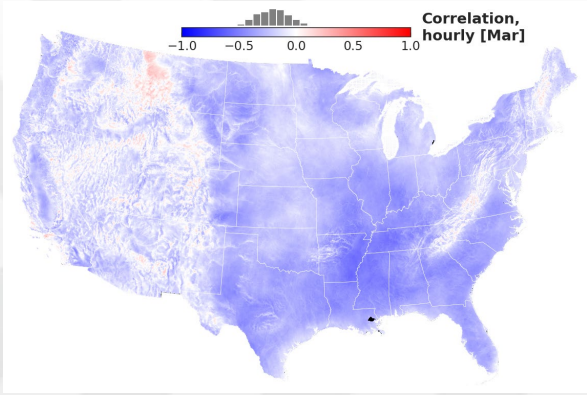
# Seasonal variation in hourly correlated PV-Wind power production

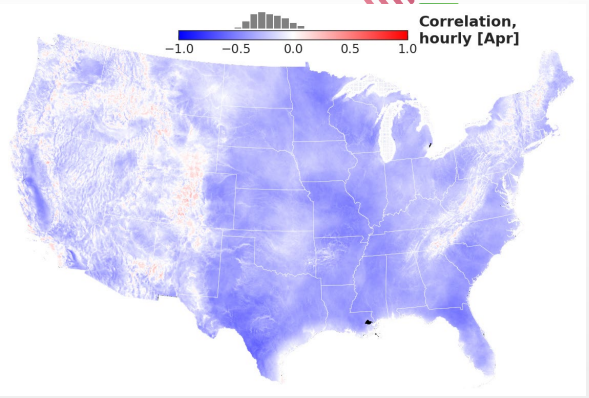
Monthly Pearson

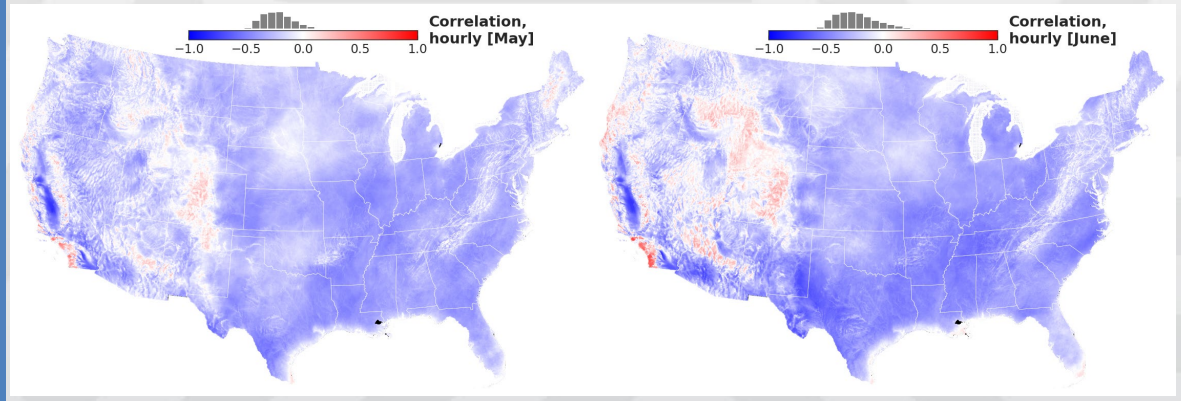






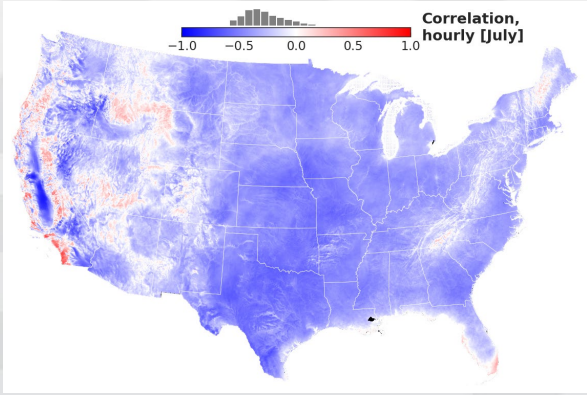


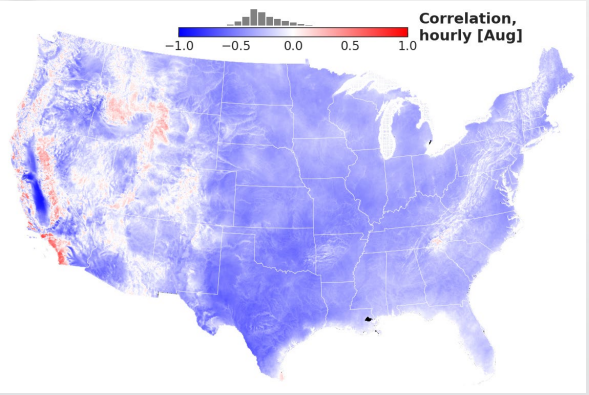



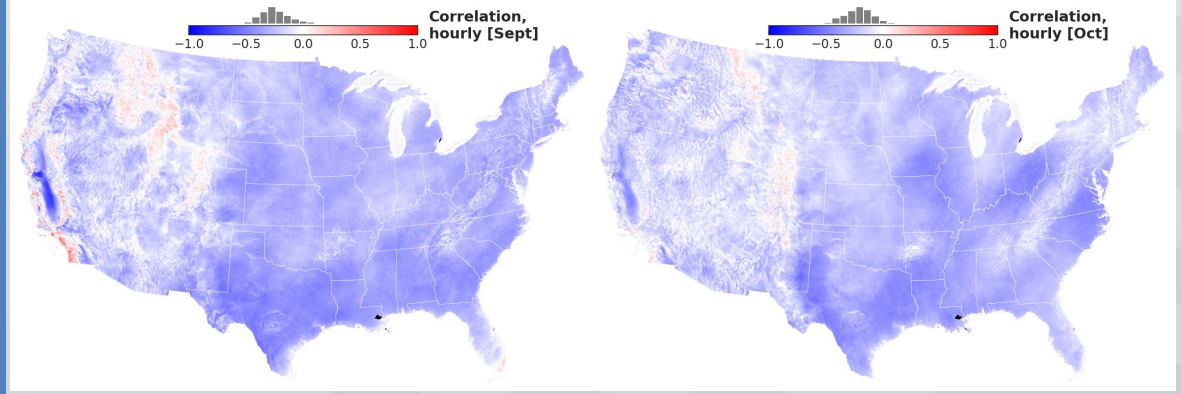







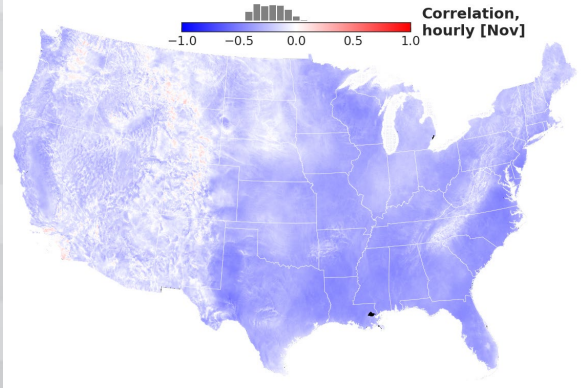


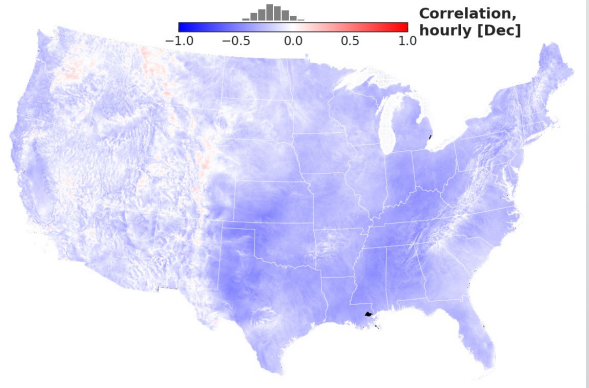









# FlexPower Control functions

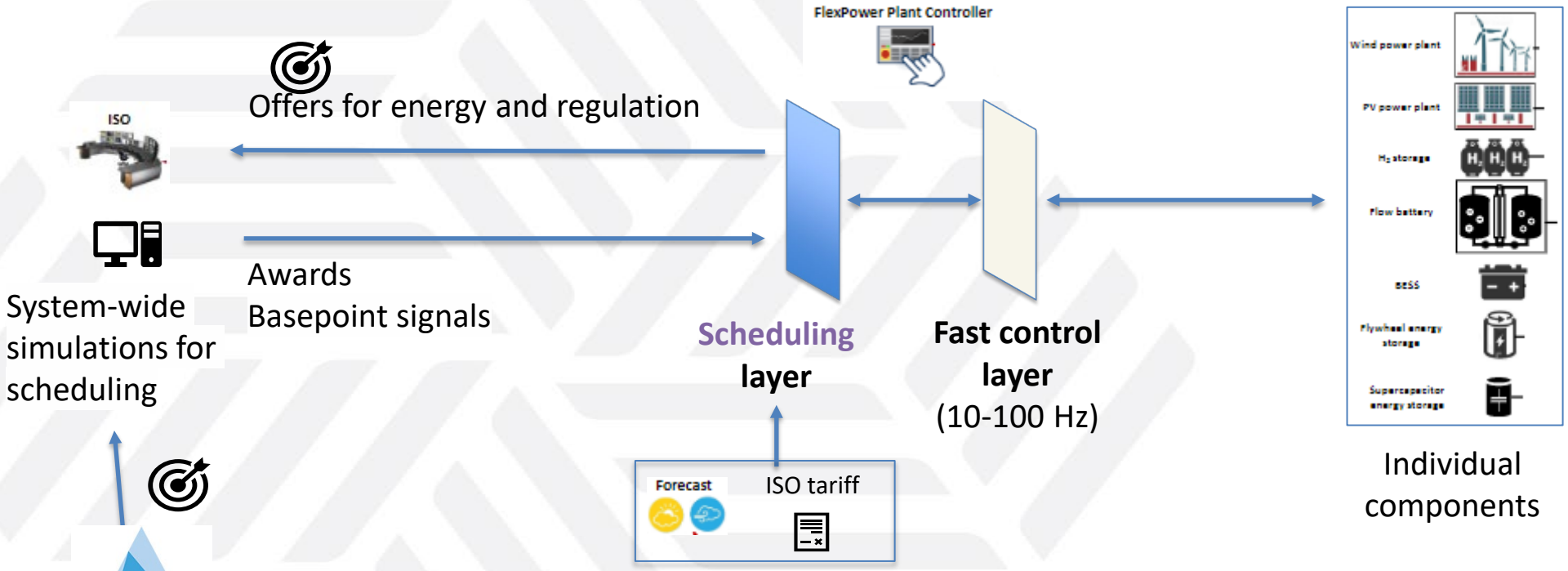
- Dispatchable energy services and flexibility services with resource forecast:
  - Reduced curtailment, increased energy production, and higher capacity factors from the same plant footprints
  - Fully dispatchable, load-following operation using long (hours, days)- and short-term (5 min) production forecasts, and capability to bid into day-ahead and real-time energy markets (like conventional generation), forecast error mitigation
  - Capacity and flexibility services
  - Aggregate plant level ramp limiting, variability smoothing, and cloud and wake impacts mitigations
  - Various strategies to provide different types of reserve and flexibility products (head room estimation for wind and solar is implemented)
- Essential and advanced reliability services:
  - Automatic generation control (AGC) and primary frequency response
  - Fast frequency response (FFR) and synthetic inertia
  - Superior plant-level 4-quadrant dynamic reactive power/voltage control
  - Stable operation with weaker grids
  - Enhanced fault ride-through performance/recovery profiles, programmable reactive current injection
  - Advanced controls for damping all types of power system oscillations, control interactions, and resonances
- Transient performance
- Resiliency services:
  - Grid-forming, black start, participation in grid restoration
  - Islanded operation

Optimizer

Fast Services Controller

# FLEXPOWER "MARKET INTERFACE"

## The two-layer FlexPower Plant Controller

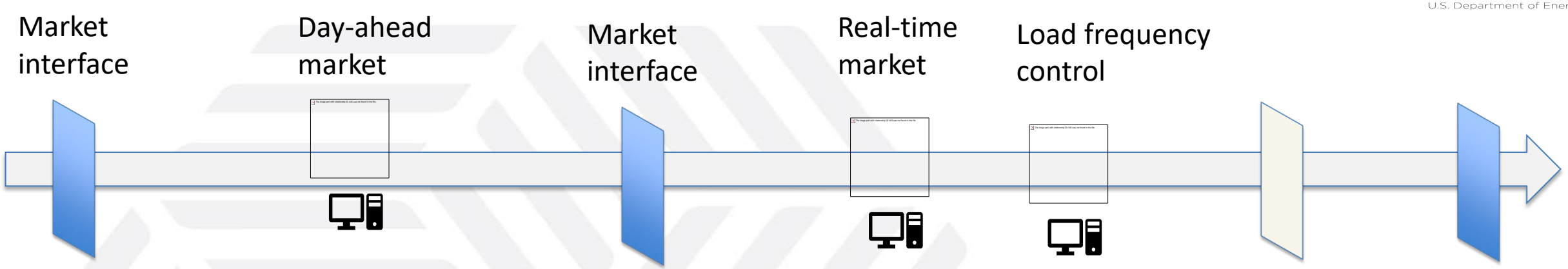



**Features of the scheduling layer**

Scheduling layer or Market interface

- Does not try to predict prices
- Accounts for potential forecast error
- Assumes ISO-management of energy constraints

# Timeline of FLEXPOWER “MARKET INTERFACE”




First version of python code on github

First version of python code on github

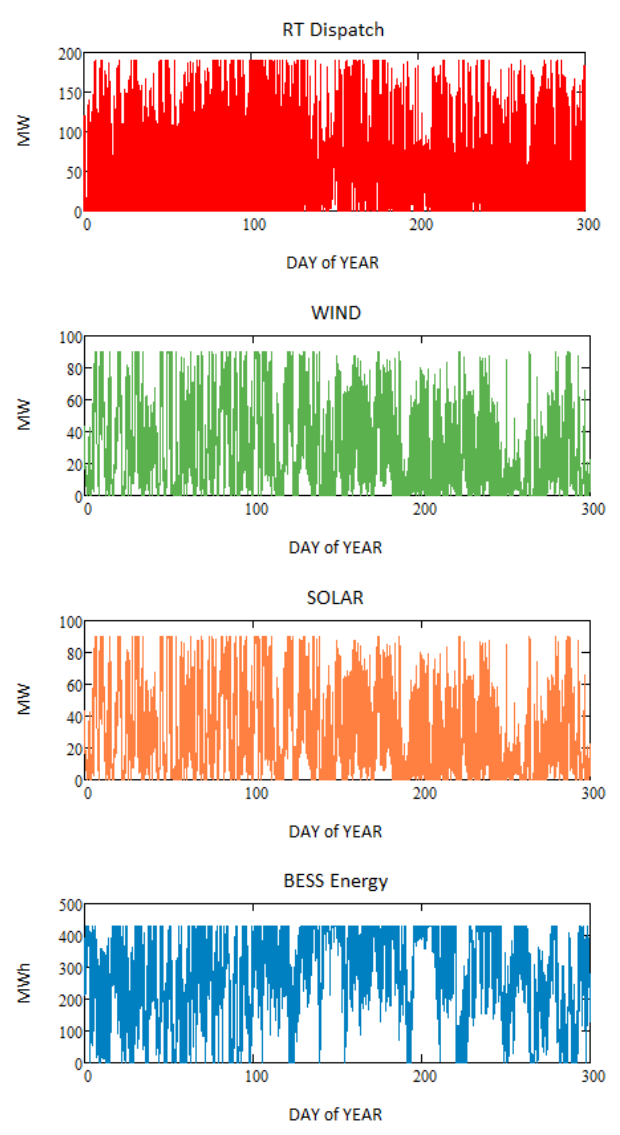
First version of python code on github

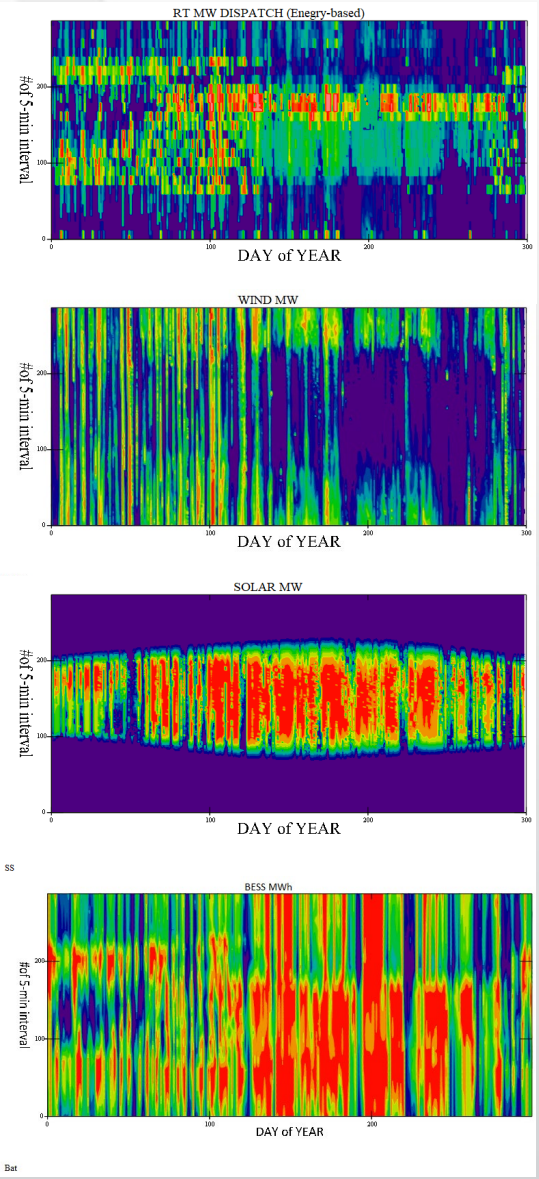
# Hybrid wind-PV-storage plant model – 300-day simulation

100 MW wind

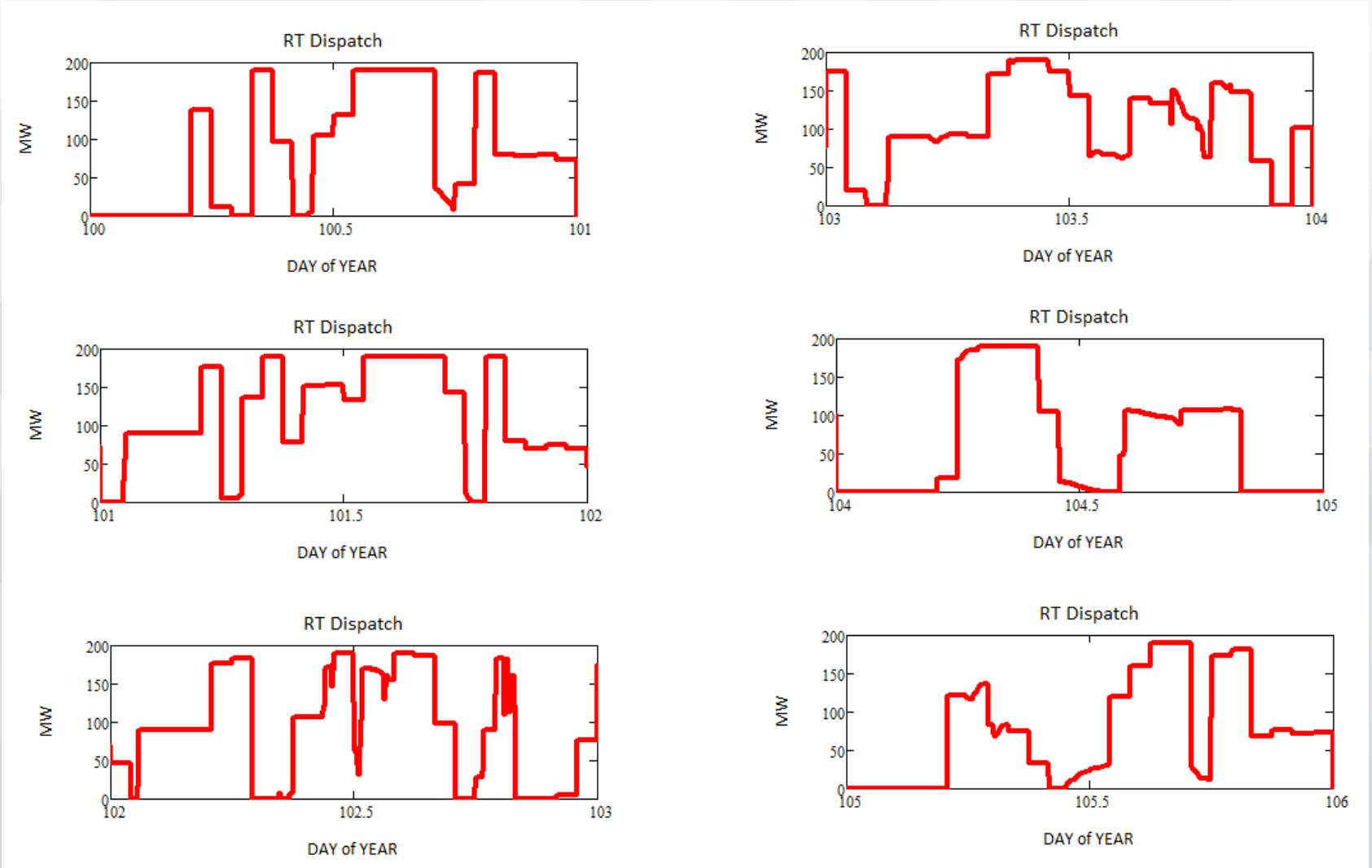
90 MW PV

100 MW / 4 hr storage

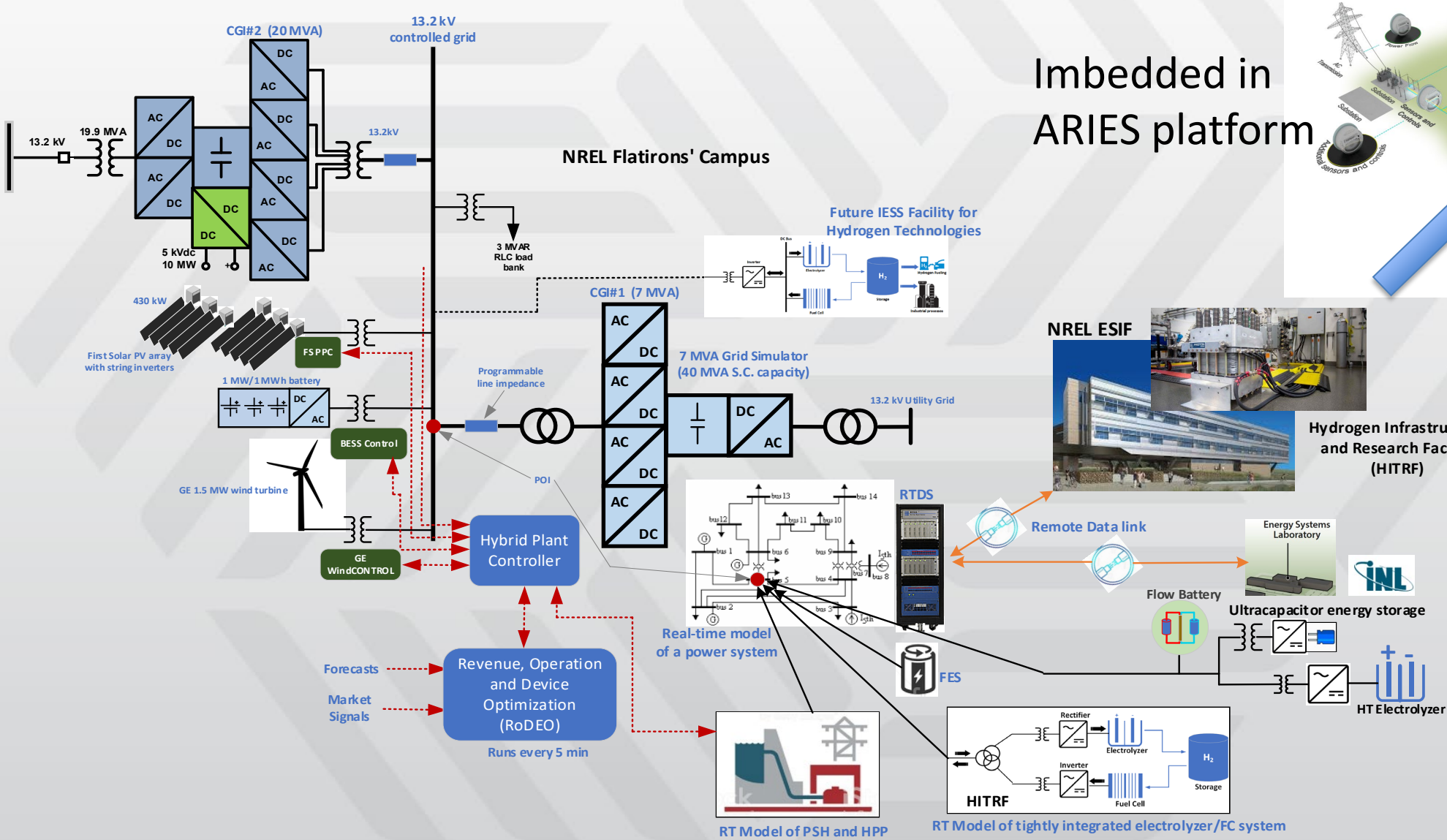


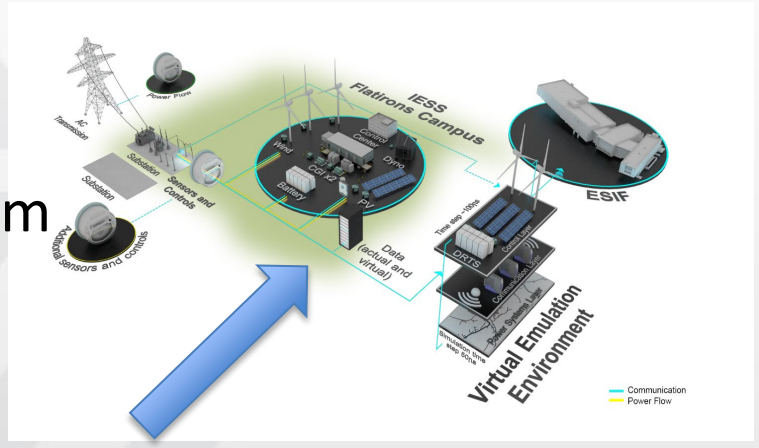
# Real-time 5-min dispatch – example days



# FlexPower Hybrid Plant Demonstration Platform




Imbedded in ARIES platform





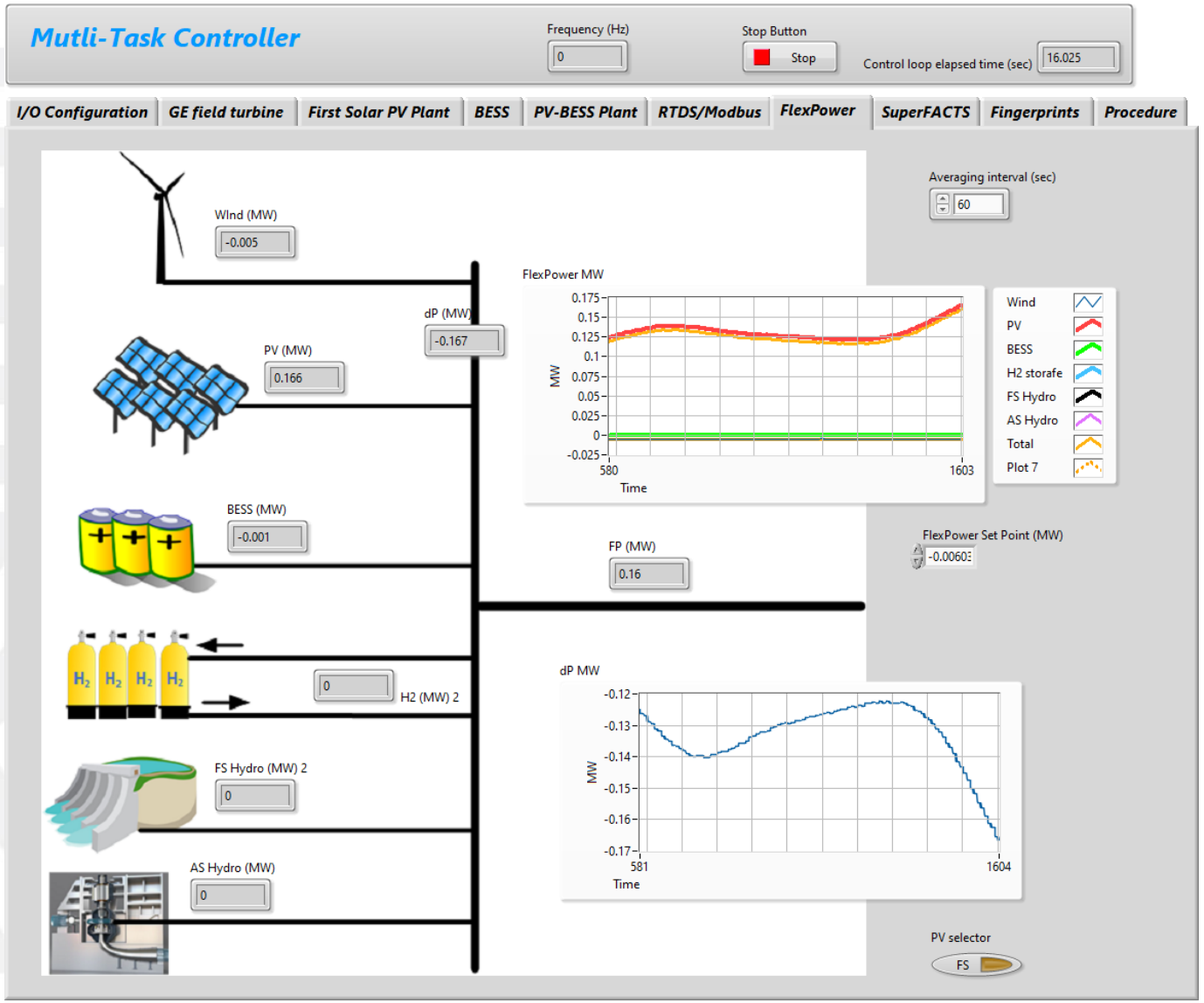

NREL ESIF

Hydrogen Infrastructure and Research Facility (HITRF)

Additional assets:

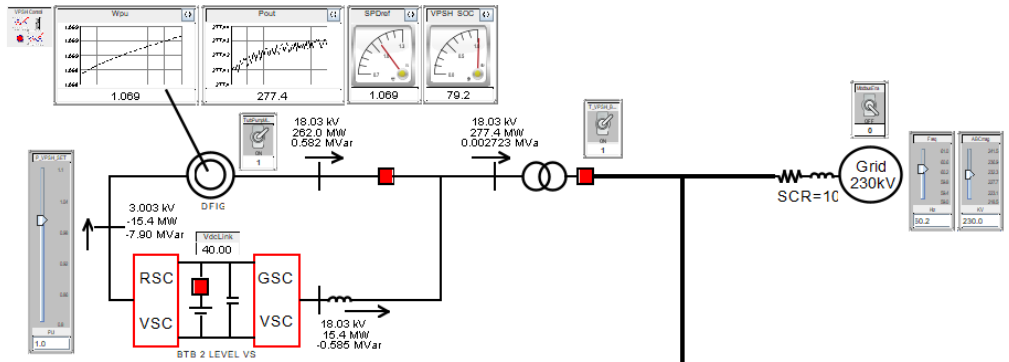
- 20 MW CGI (2021)

# Multi-task Controller Interface

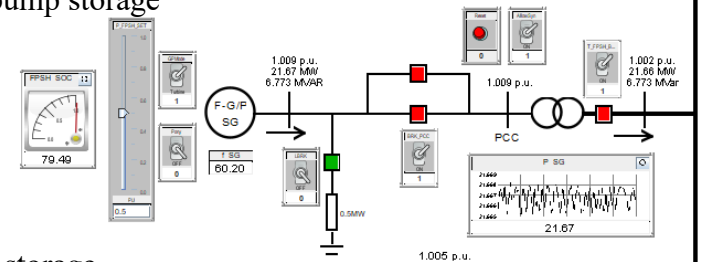


# Test platform

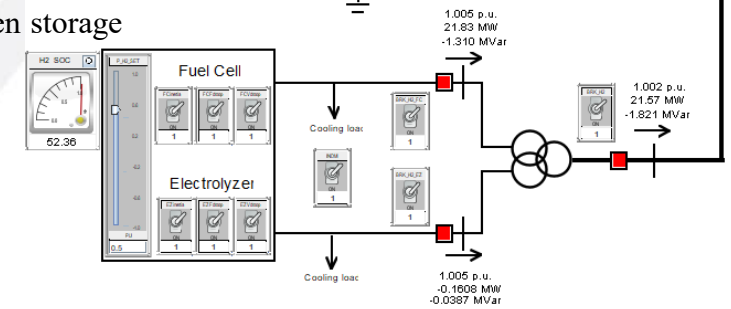

300 MVA Adjustable speed pump storage hydro unit
3000 MW.h



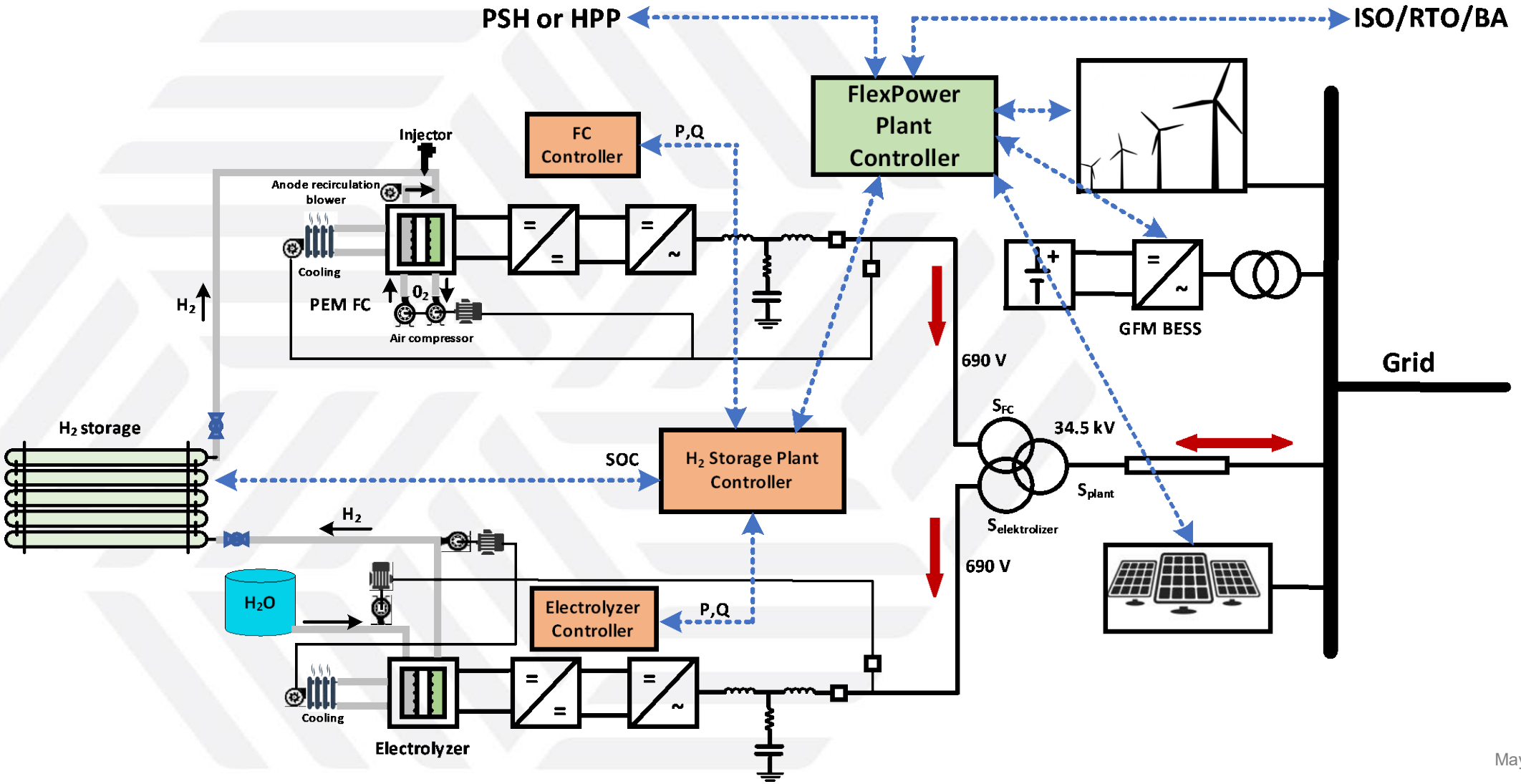

50 MVA Fixed speed pump storage hydro unit
500 MW.h



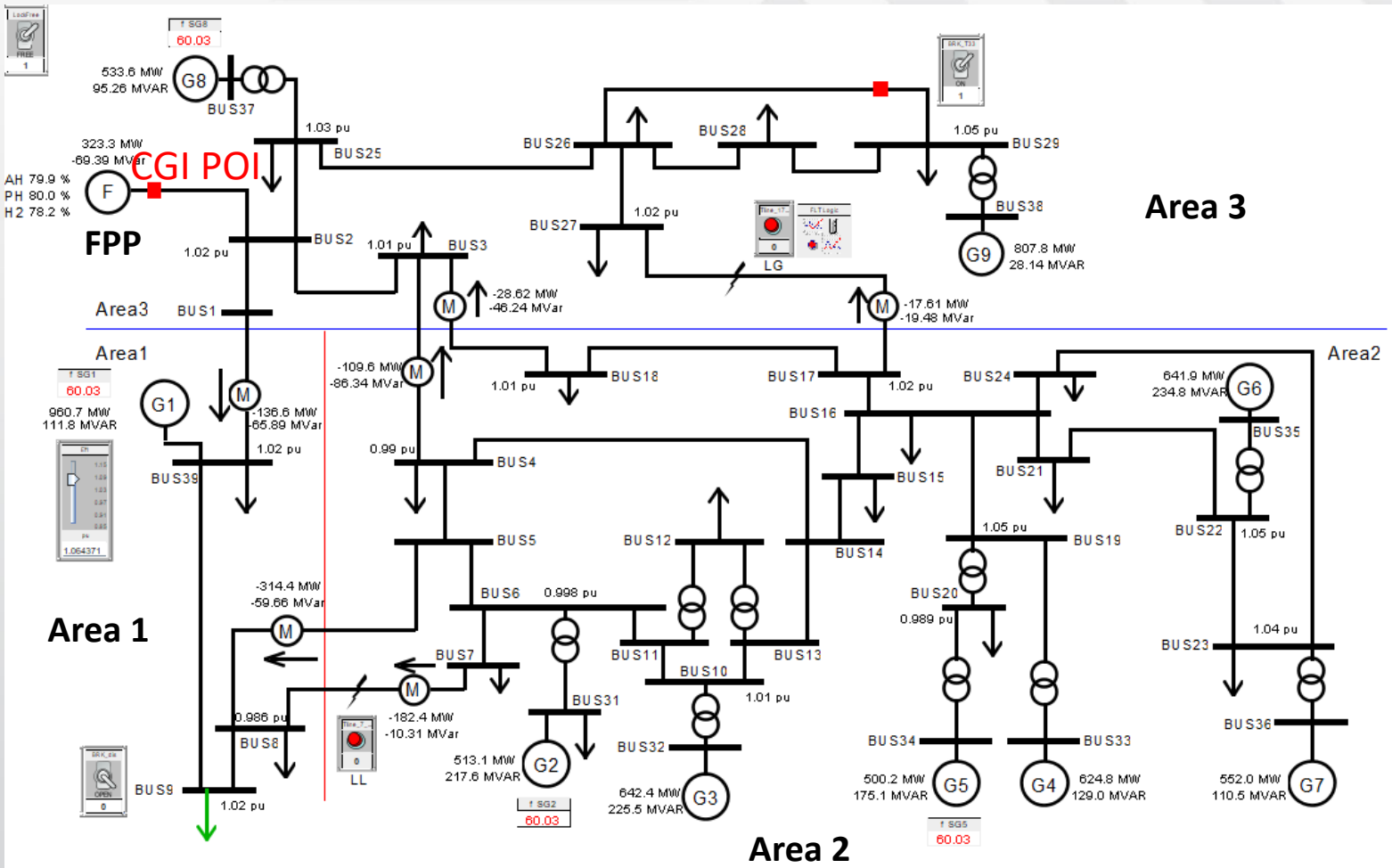

50 MVA Hydrogen storage
5 MW.h



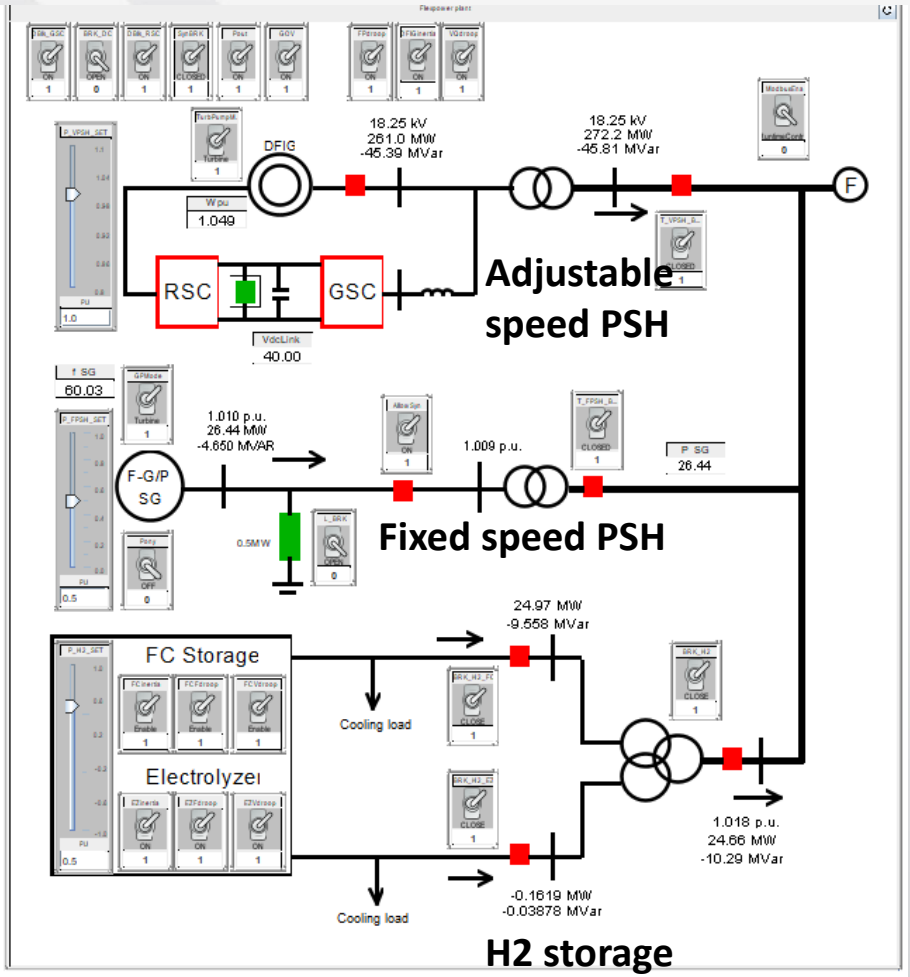
# H2 Storage Model Integrated in PHIL



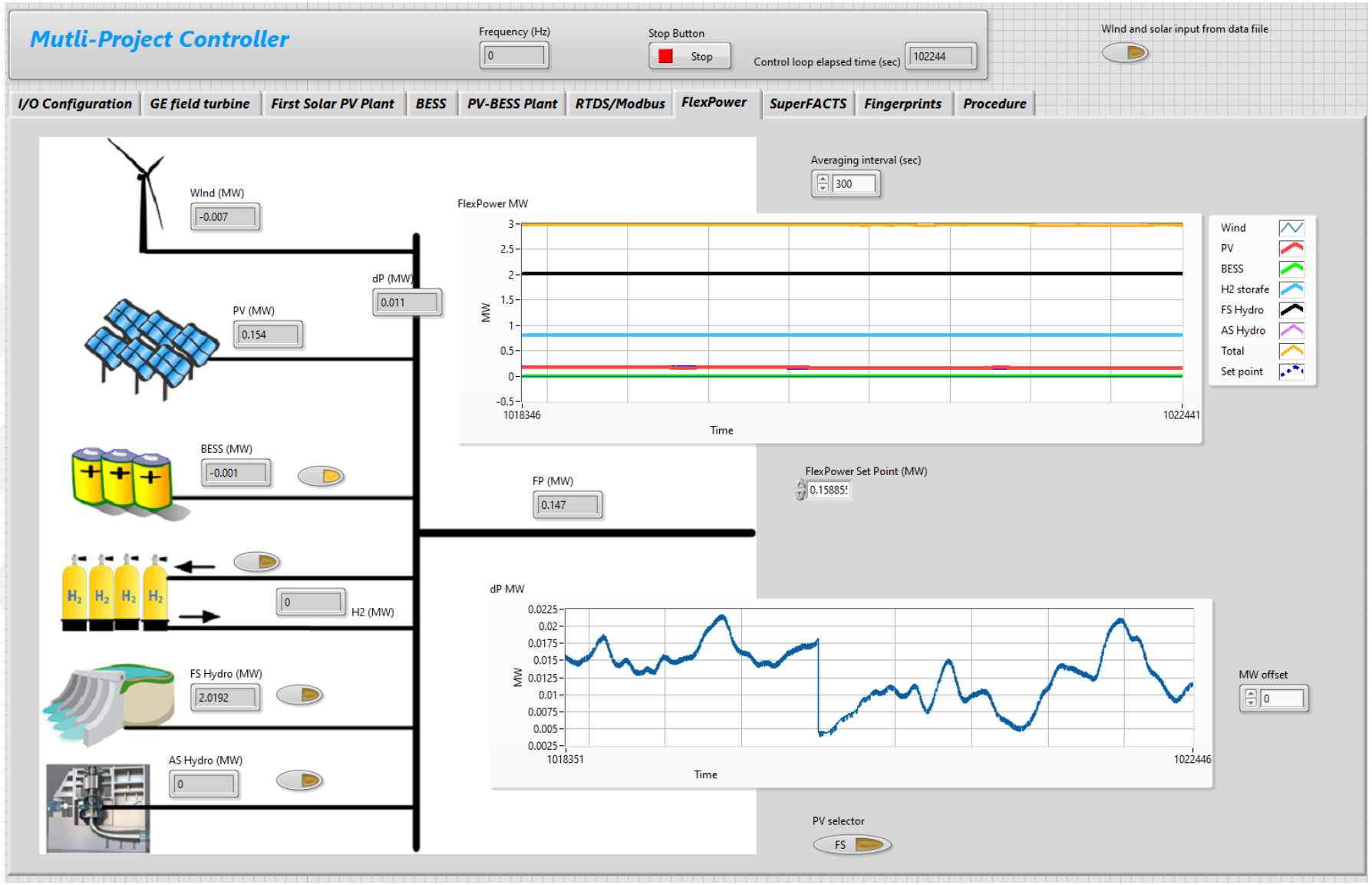
# Flexpower Plant in IEEE 39 Bus System



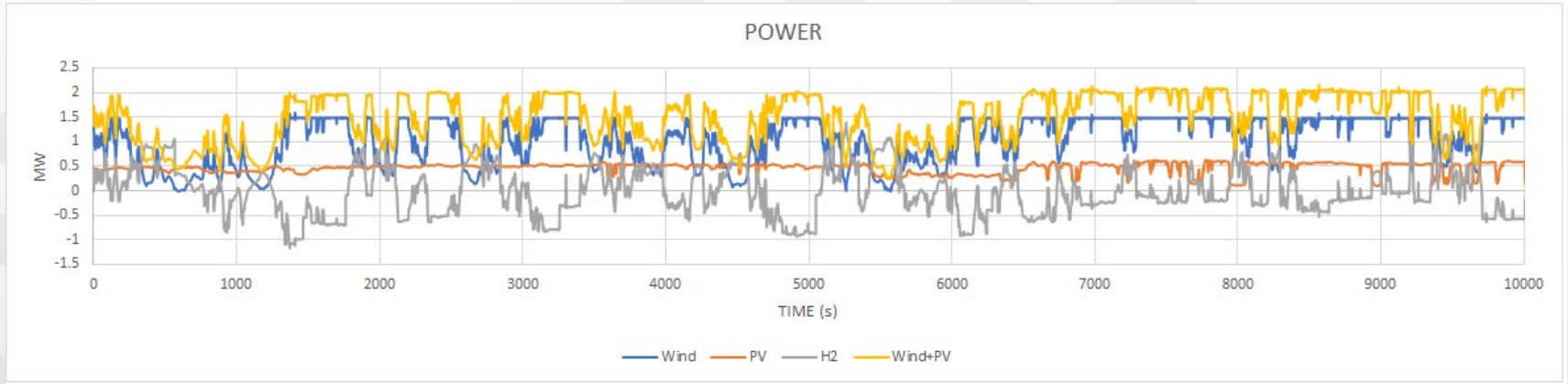

**FPP: Flexpower Plant control panel**

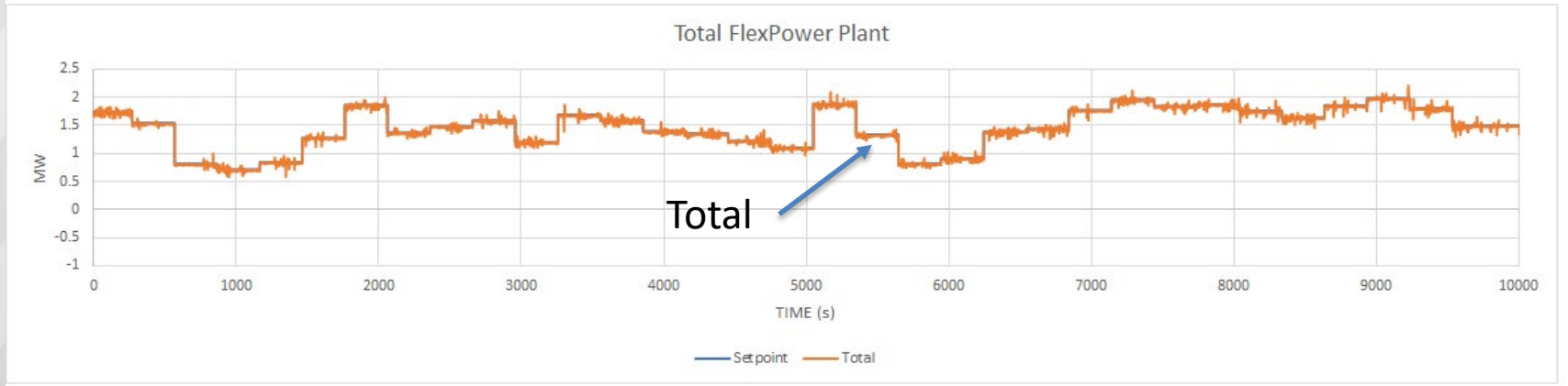


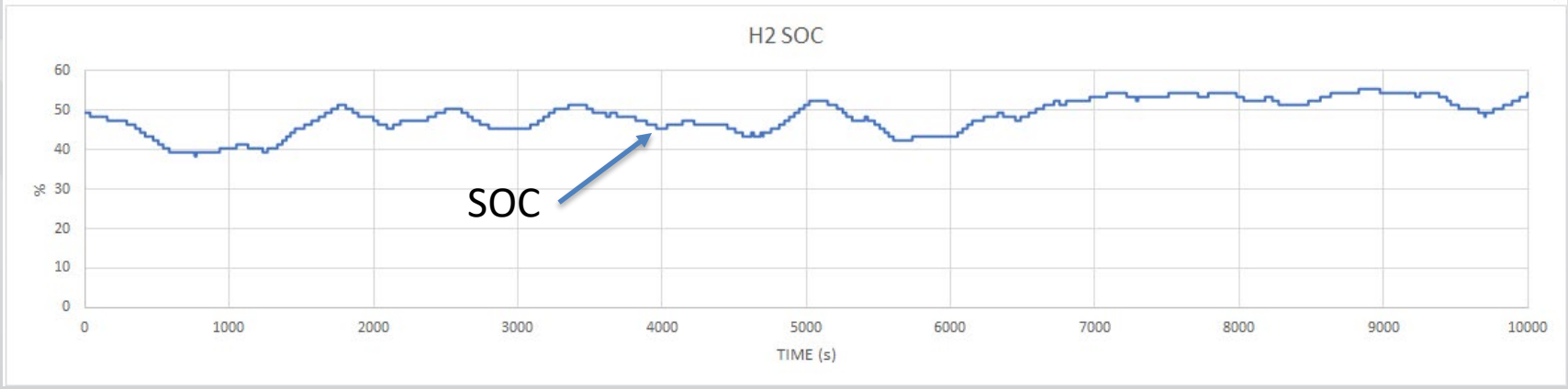
# FlexPower Controller



# Wind / PV / $H_2$ Storage plant operation at Flatirons Campus



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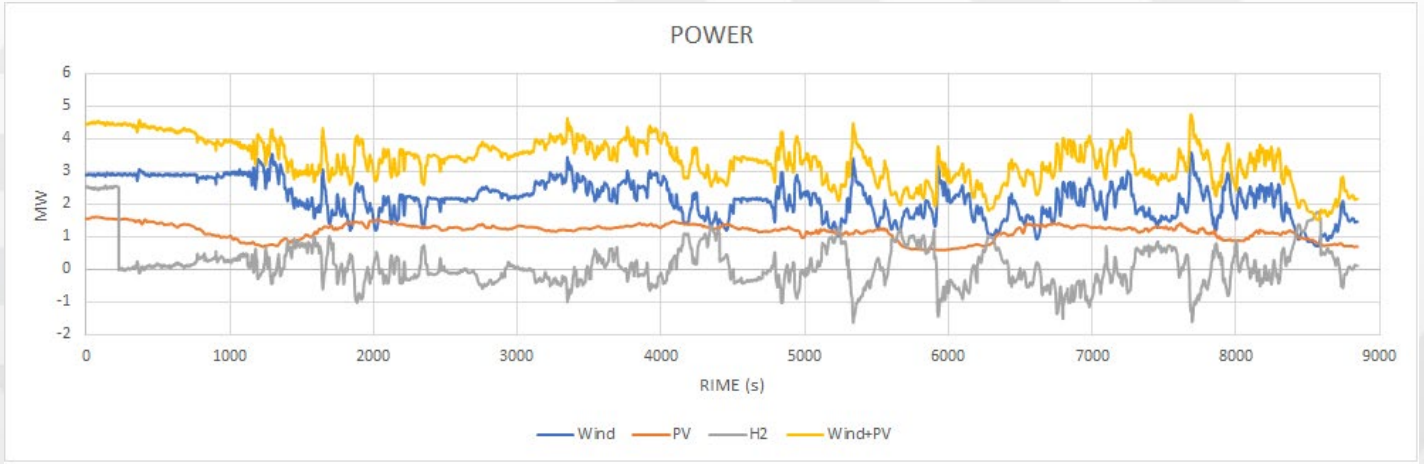
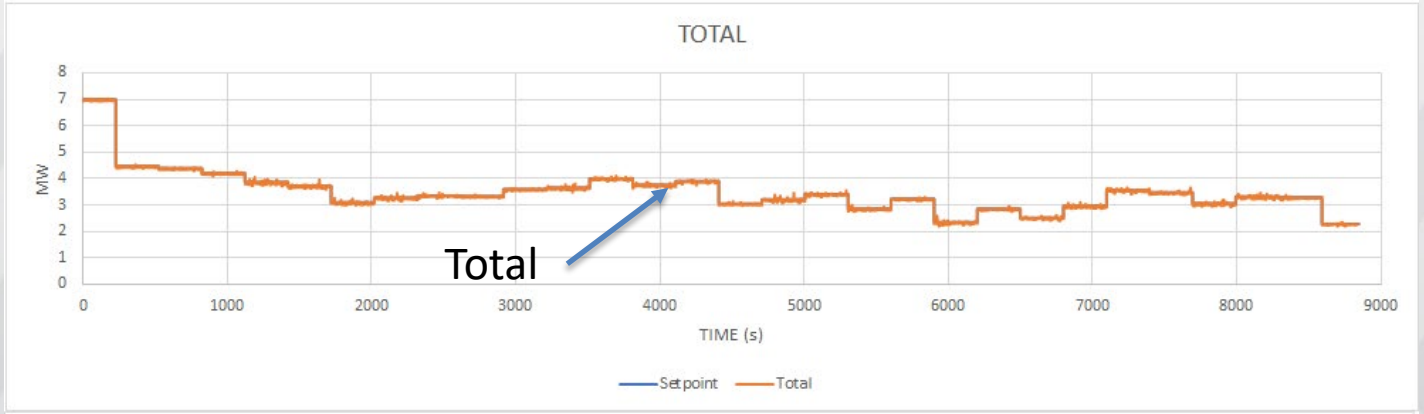
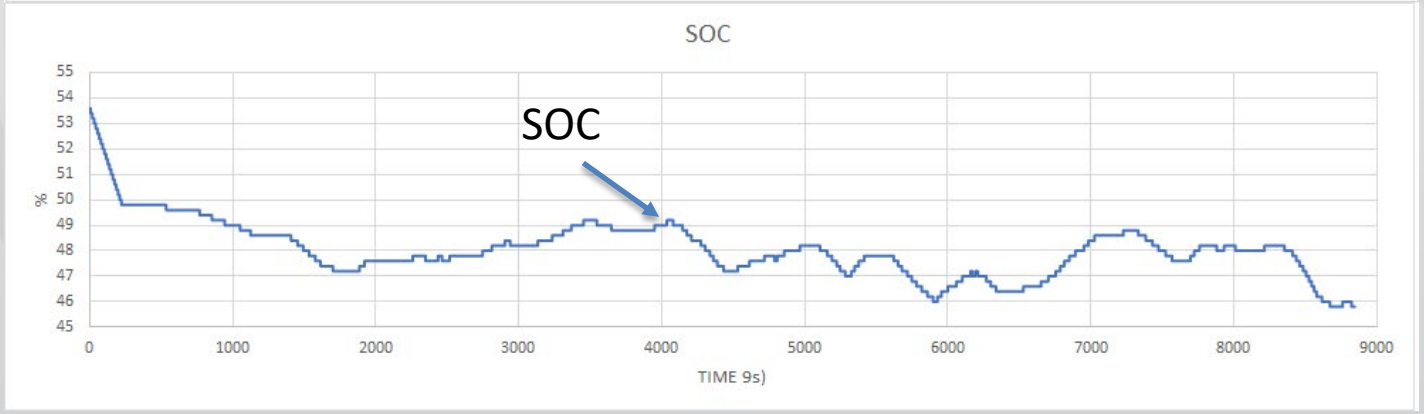
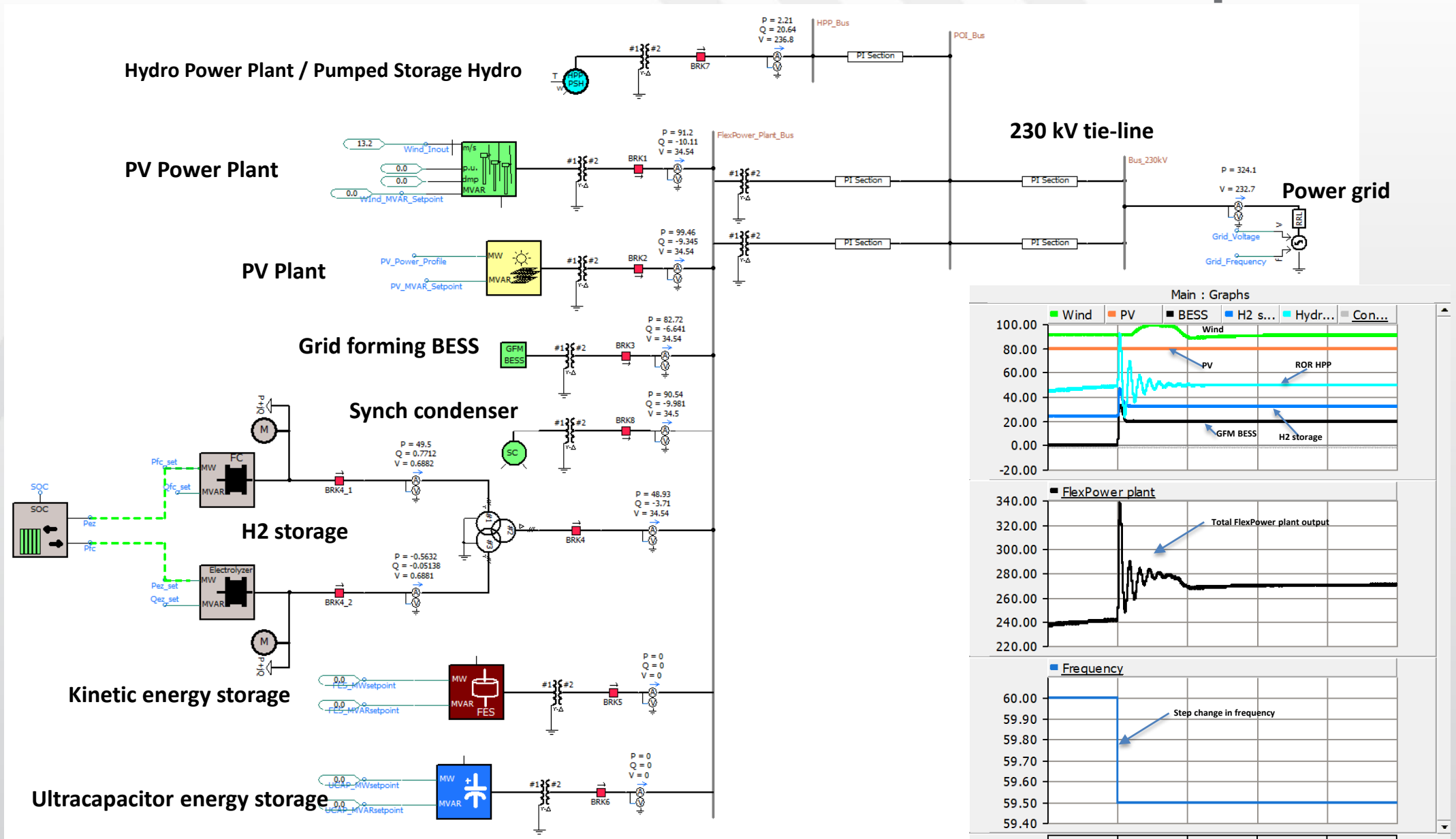


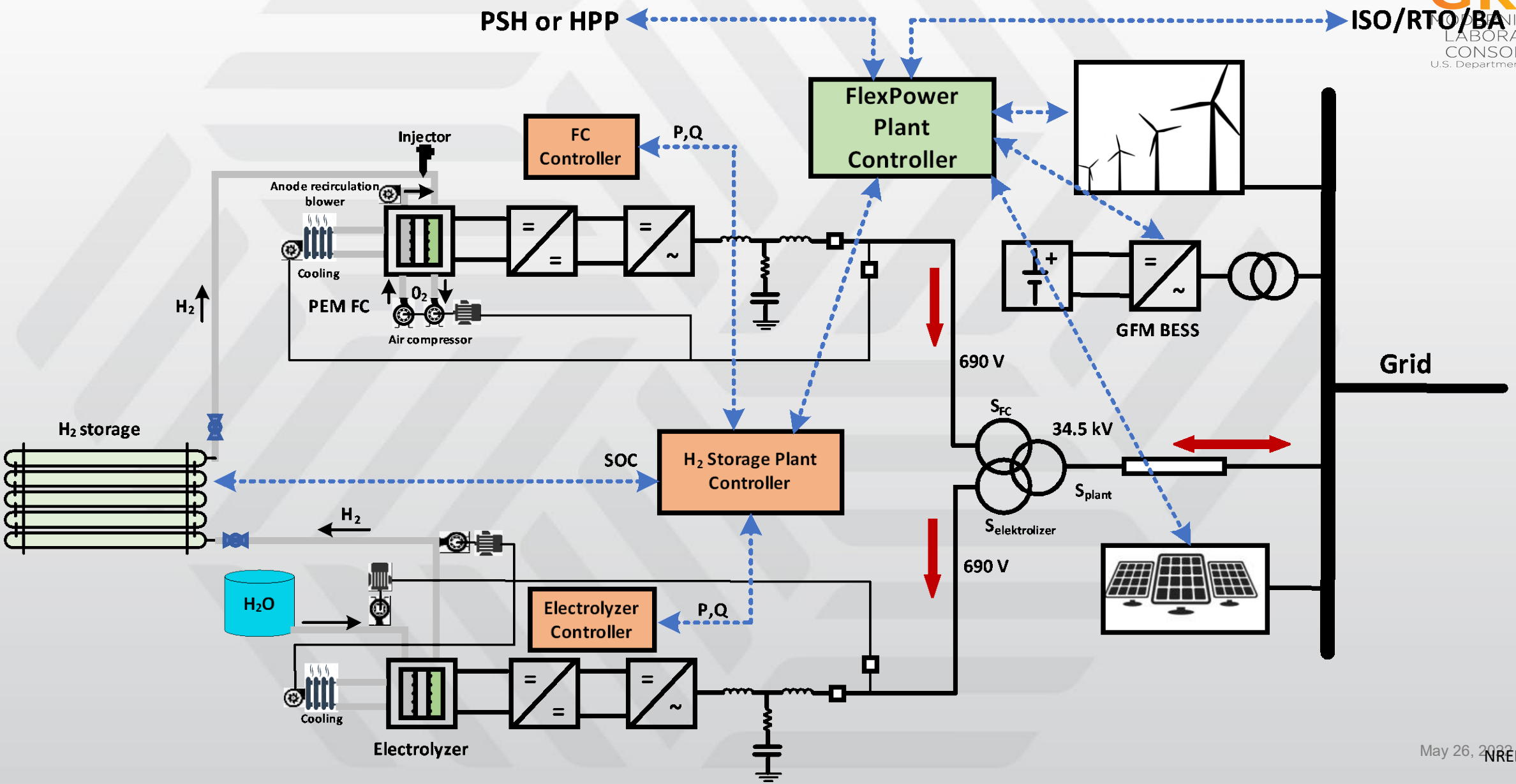



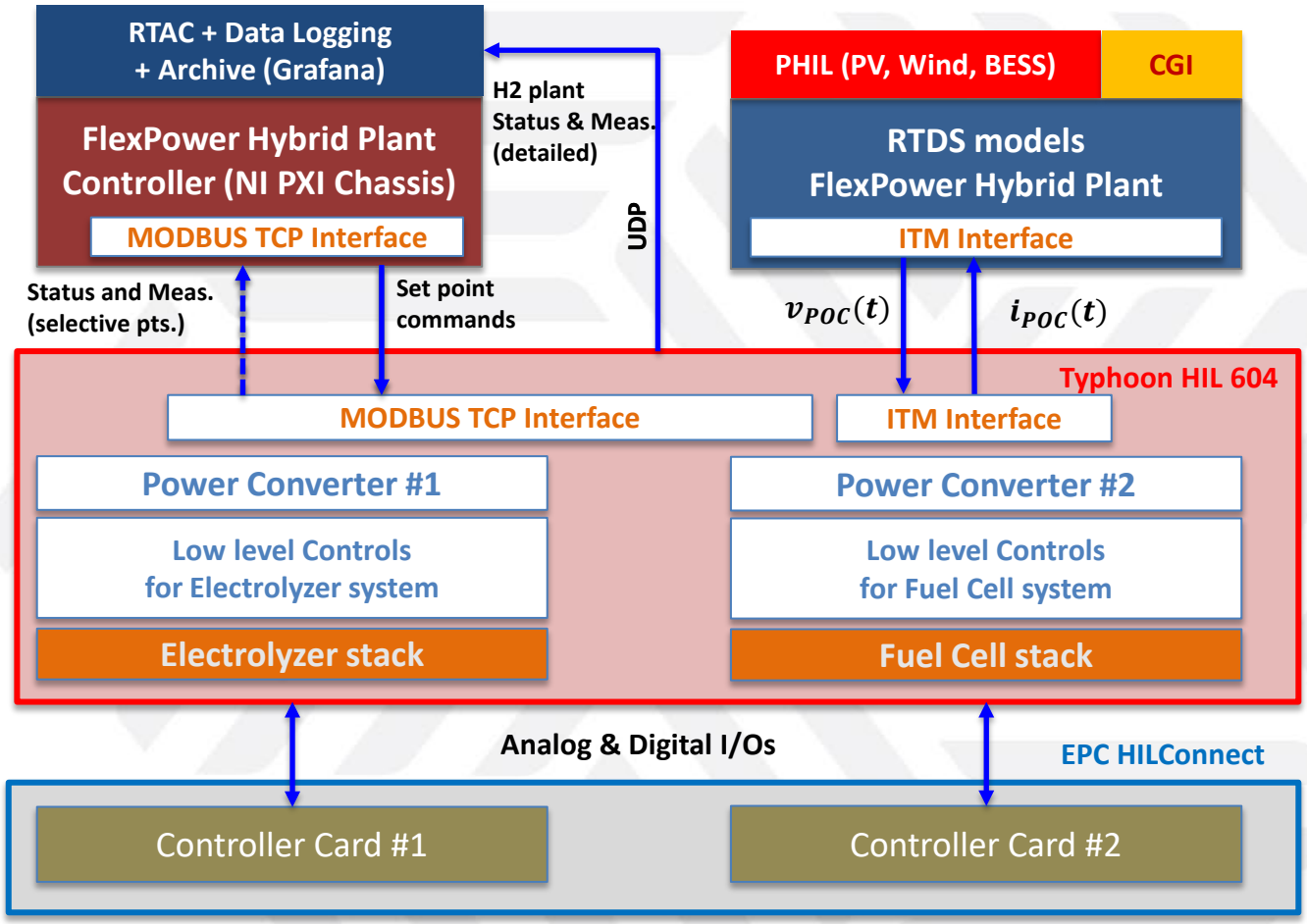
# PSCAD Model of FlexPower Plant – all components

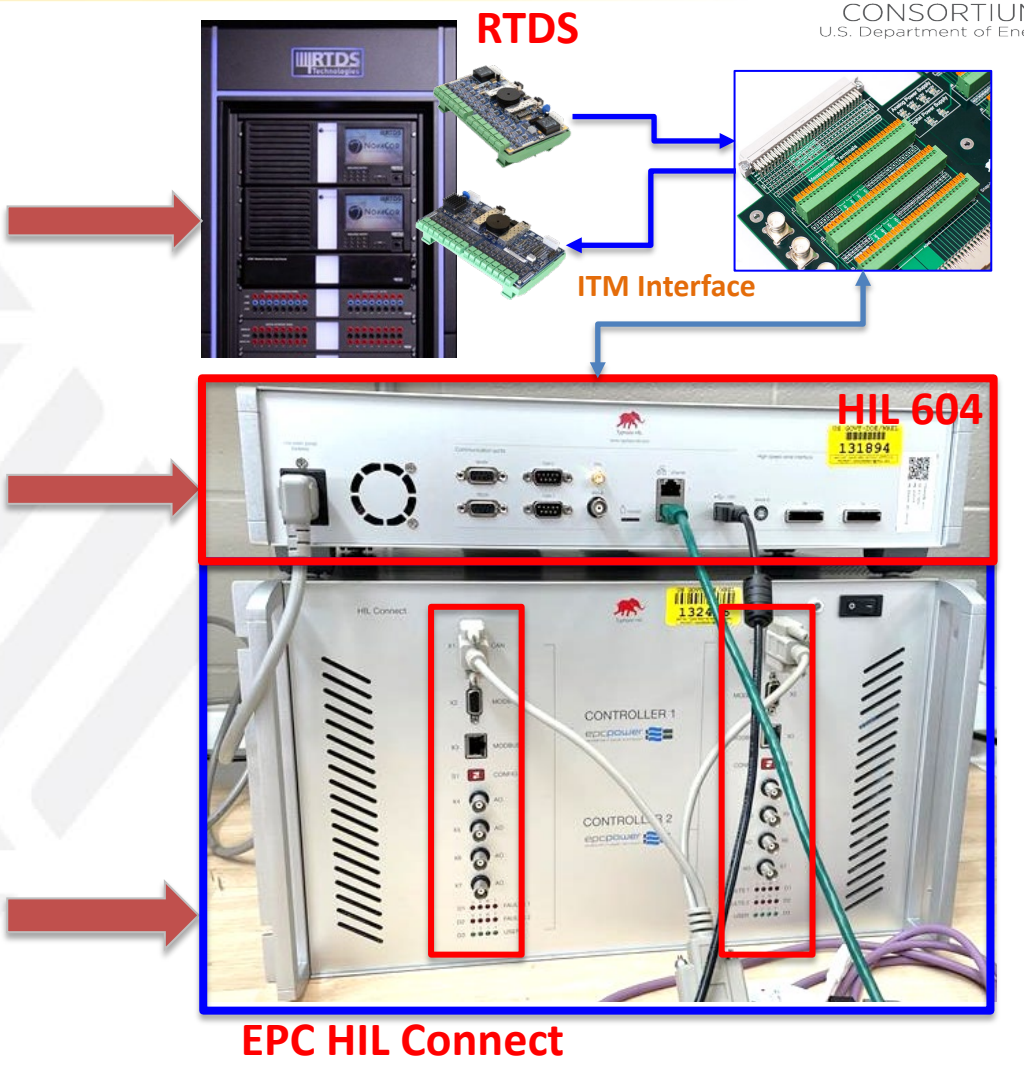


# $H_2$ storage RT model integrated in FlexPower Test Platform



# RTDS-Typhoon HIL Interfacing and FlexPower H2 CHIL



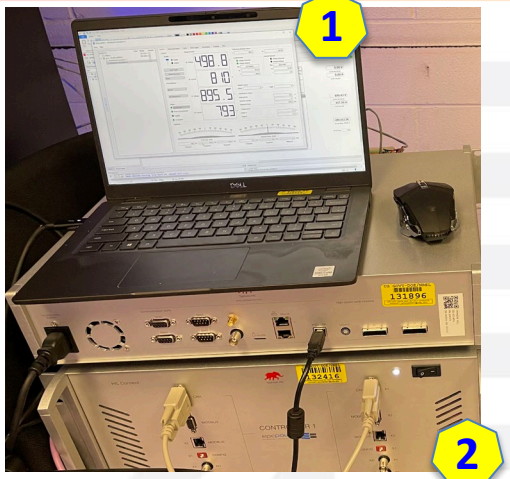




- Tested CHIL with RTDS (IEEE39 bus) EPC HIL Connect and HIL 604.

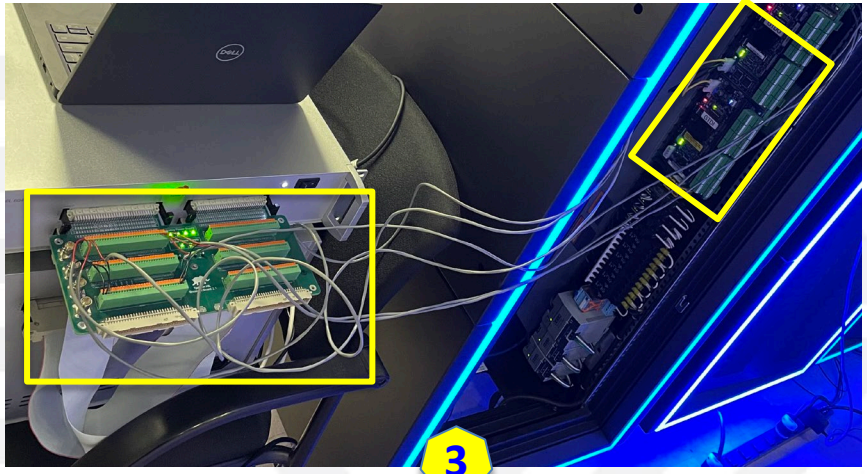
# RTDS-Typhoon HIL and HILConnect Integration

## Setup at NREL ARIES for H2 Electrolyzer and Fuel Cell System CHIL

GRID MODERNIZATION LABORATORY CONSORTIUM
U.S. Department of Energy

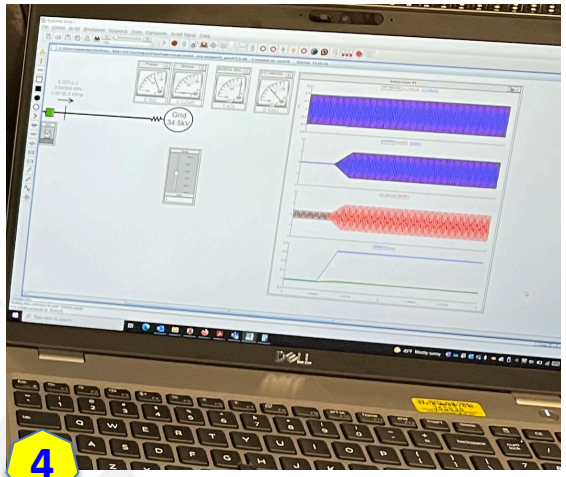



**Typhoon HIL Emulator + EPC Connect**




**Typhoon HIL Interface Board**

**RTDS GTAO & GTAI**

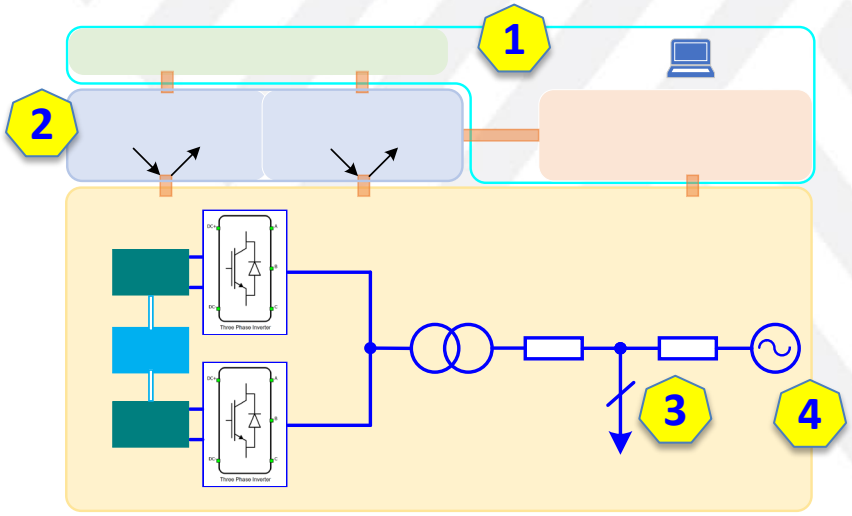


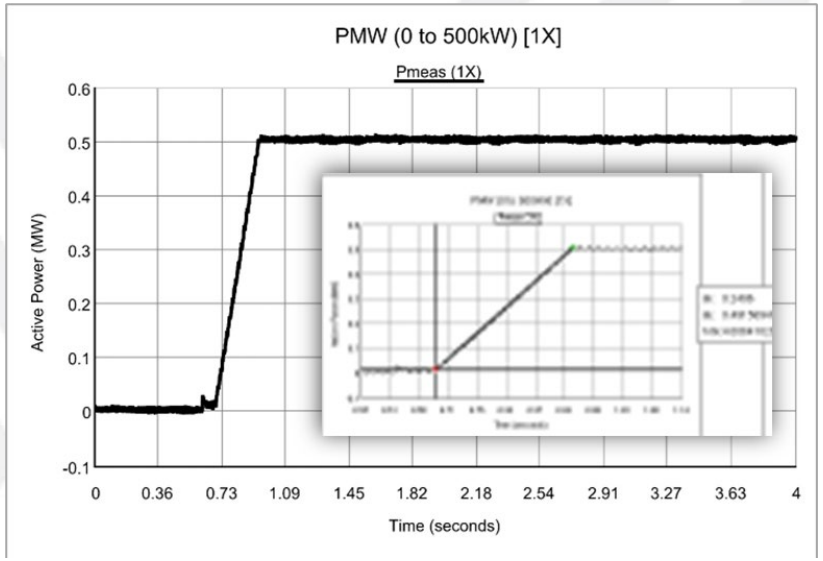

**RTDS RSCAD**

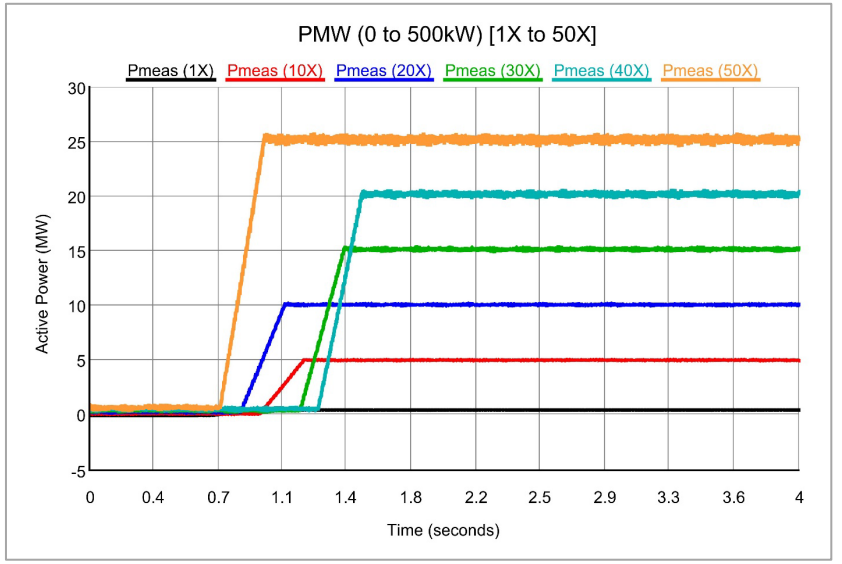
Power command:
0 to +500kW
(Fuel Cell Gen.)

Ramp rate (true):
4 MW/s

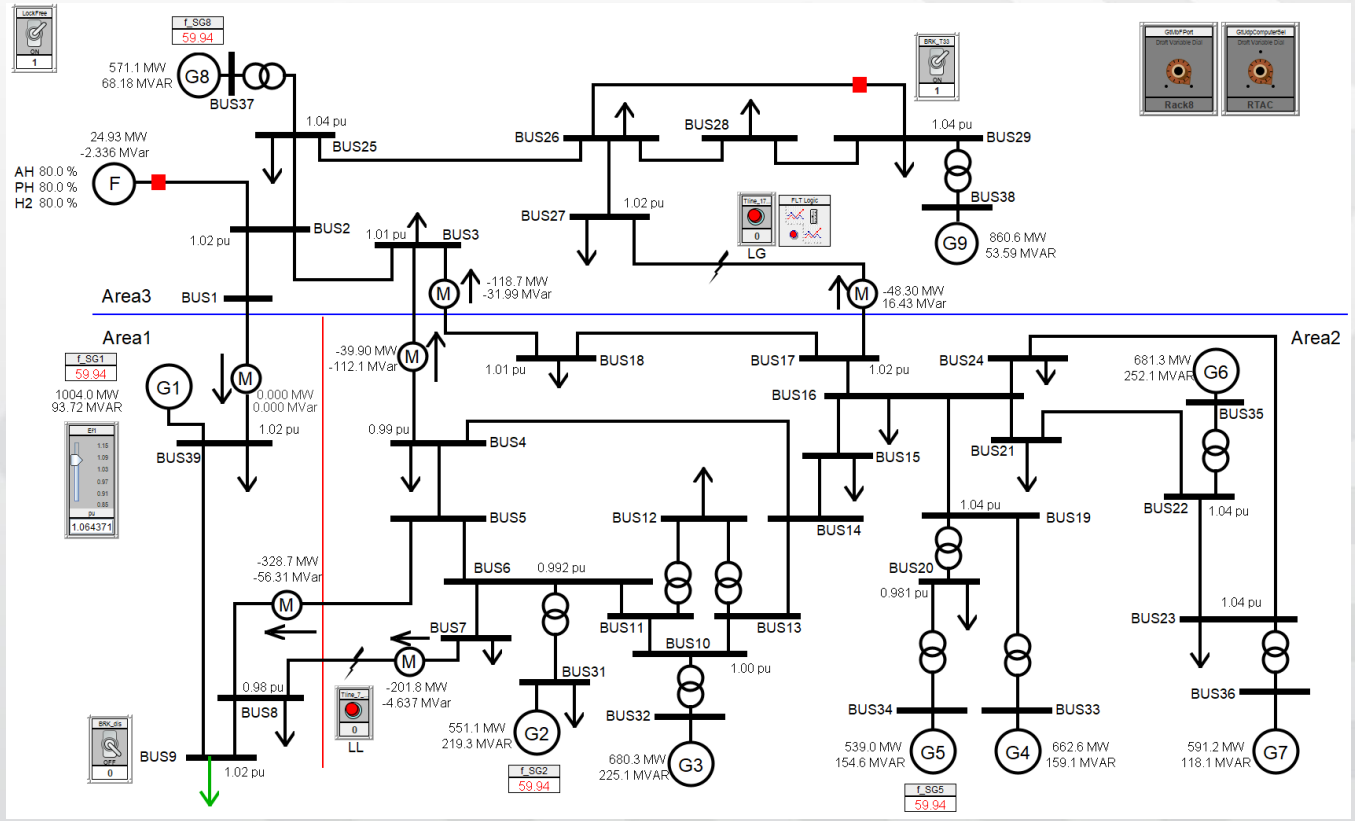
Vrms at PCC:
< 1.05 per unit

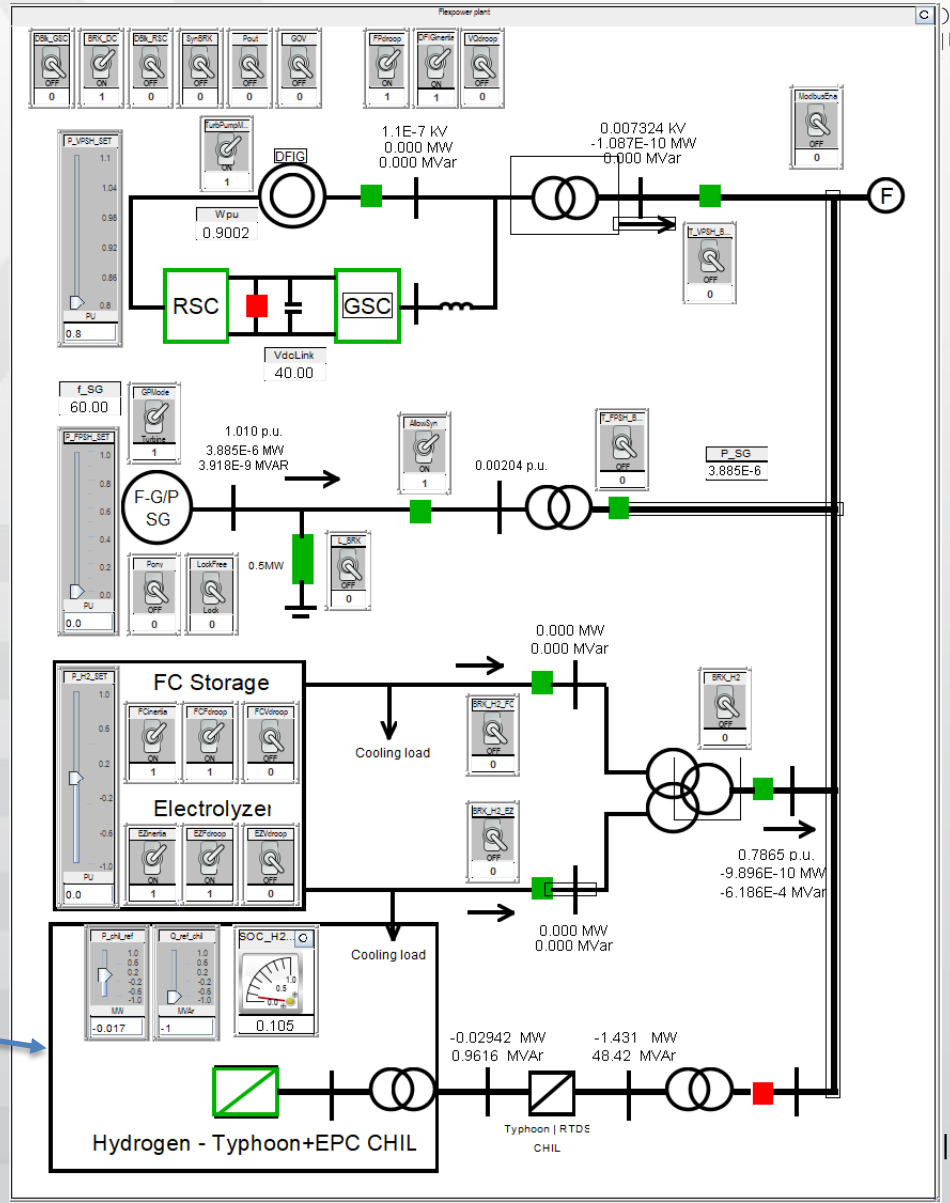


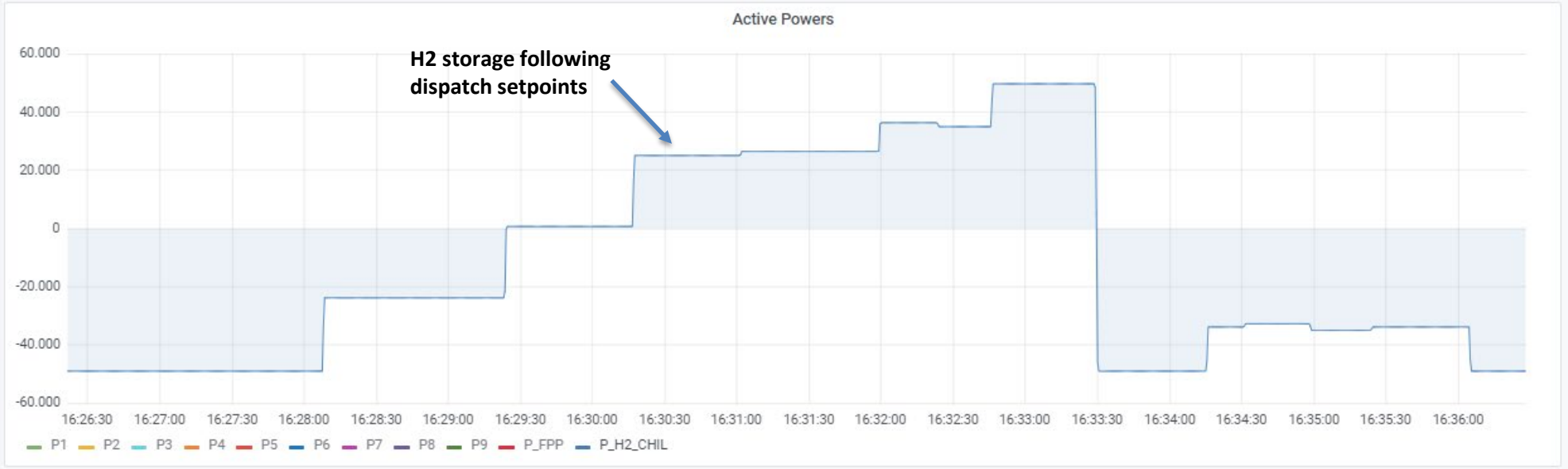
# IEEE39 bus model + Flexpower

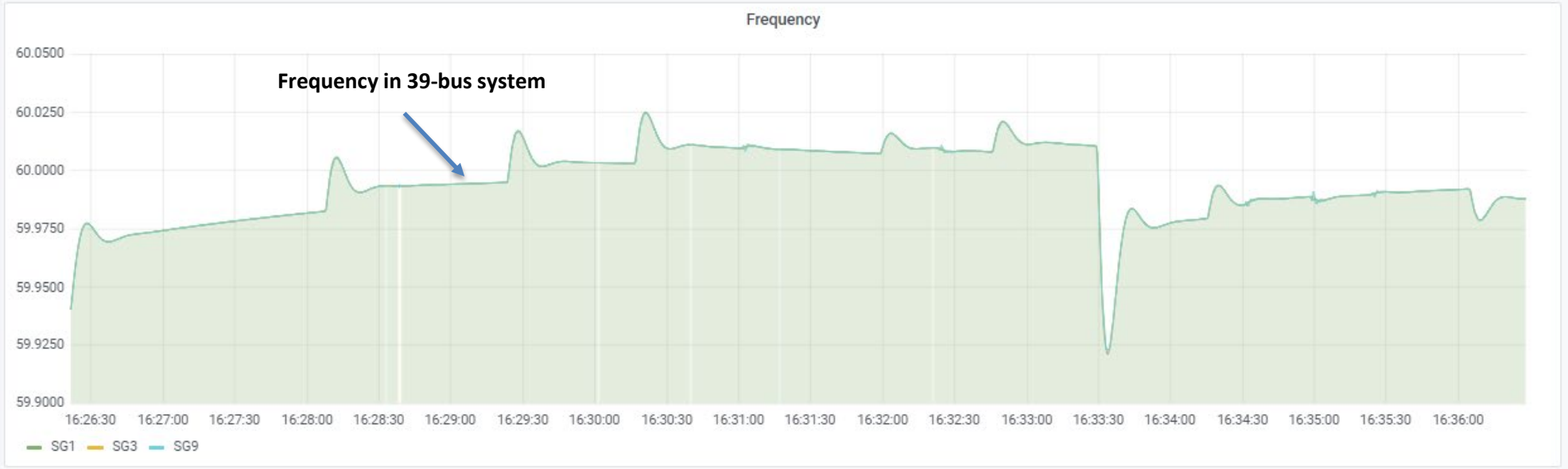


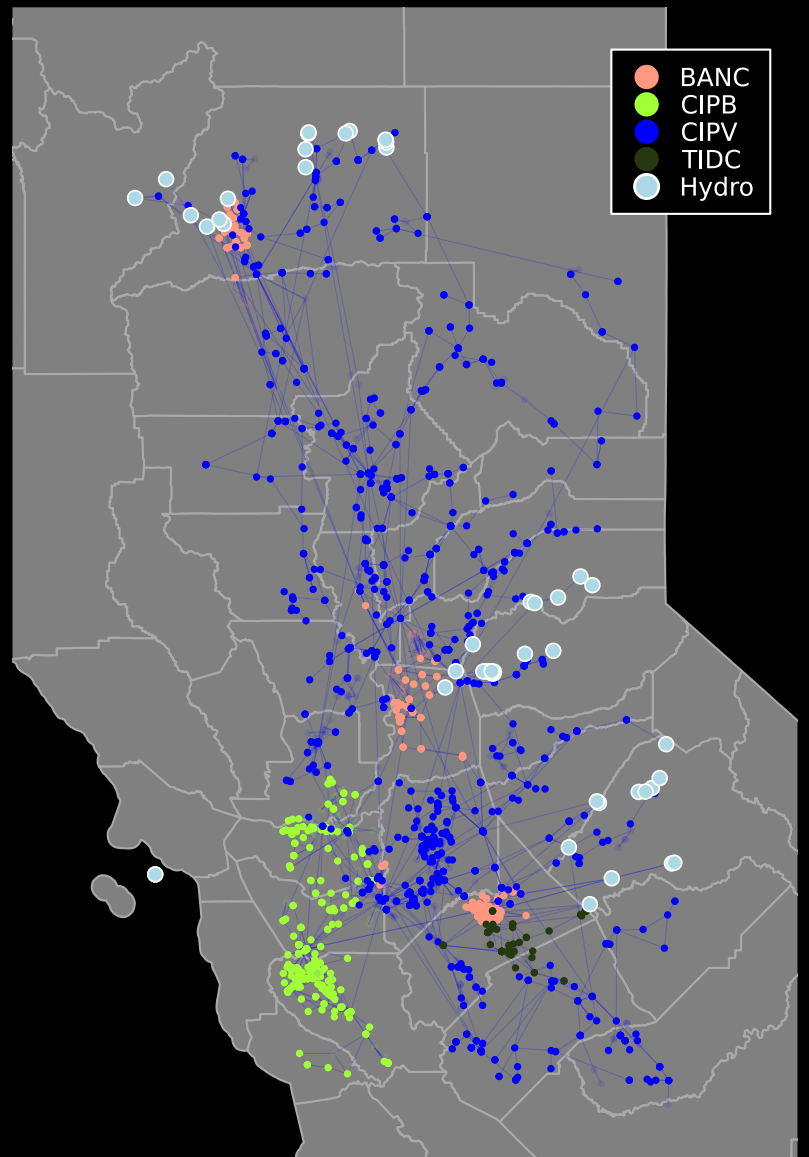

Added Typhoon CHIL node

# H2 Storage Operation in IEEE39 bs system – PHIL setup



# Northern CA Test System: Integration Study for FlexPower Plants




```
julia> norcal_sys
System
```

| Property | Value |
|---|---|
| System Units Base | SYSTEM_BASE |
| Base Power | 100.0 |
| Base Frequency | 60.0 |
| Num Components | 8035 |

**Static Components**

| Type | Count | Has Static Time Series | Has Forecasts |
|---|---|---|---|
| Arc | 2413 | false | false |
| Area | 4 | true | true |
| Bus | 1969 | false | false |
| GenericBattery | 5 | false | false |
| HydroDispatch | 232 | true | true |
| Line | 1463 | false | false |
| LoadZone | 4 | false | false |
| MonitoredLine | 344 | false | false |
| PowerLoad | 658 | true | true |
| RenewableDispatch | 60 | true | true |
| ThermalStandard | 153 | false | false |
| Transformer2W | 730 | false | false |

**Time Series Summary**

| Property | Value |
|---|---|
| Components with time series data | 950 |
| Total StaticTimeSeries | 1235 |
| Total Forecasts | 1235 |
| Resolution | 60 minutes |
| First initial time | 2009-01-01T00:00:00 |
| Last initial time | 2009-12-29T00:00:00 |
| Horizon | 48 |
| Interval | 1440 minutes |
| Forecast window count | 363 |

## Norcal Test System Capacity Mix