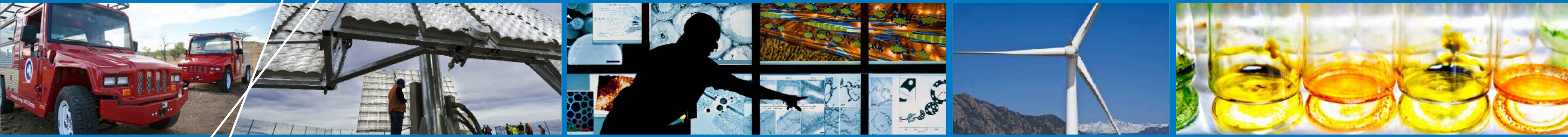
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

PV Controls Utility-Scale Demonstration Project



UVIG Fall Technical Workshop

San Diego

Barbara O'Neill, project with Vahan Gevorgian

October 14, 2015

NREL/PR-5D00-65284

Utility-scale PV Controls Demonstration Project

- **Assist in removing integration barriers, mitigating reliability impacts and decreasing integration costs**
- **Better utilization of advanced PV controls**
- **Multi-MW scale PV plant: not just energy source, but also a valuable AS provider**
- **Field testing and demonstration on a real plant, generating data to help industry**

Project Timeline and Funding

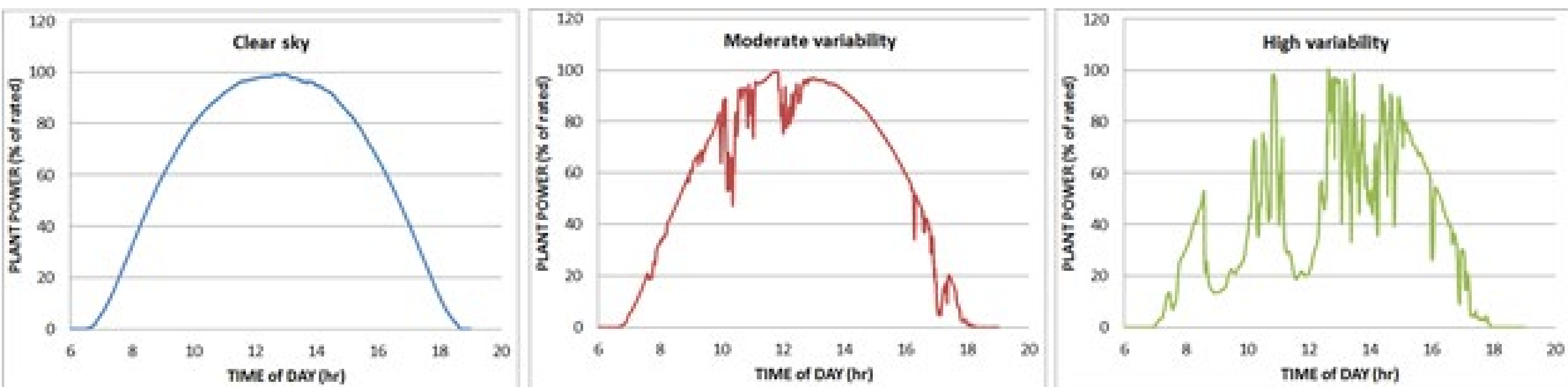
- **All funding from DOE Solar program**
- **FY14 - $50K**
  - Find industry partners
    - Two industry partners (First Solar and AES) committed
  - Develop test plans
- **FY15 - $300K**
  - Perform plant controller software upgrades
  - Conduct tests and analyze test data
  - Publish test report

Partner Selection Criteria

- **Willingness / motivation to collaborate**
- **Plant equipment suitable for purposes of the demonstration project**
  - Moderate-size utility-scale PV plant (10-30 MW)
  - PV plant with no energy storage
  - PV plant with no power electronics voltage regulating equipment (DVR, static VAR compensators, etc.)
  - PV plant with existing controls or easily upgradable
- **Generate value for local grid / system operator**
- **Test results are representative and applicable to large variety of power systems**

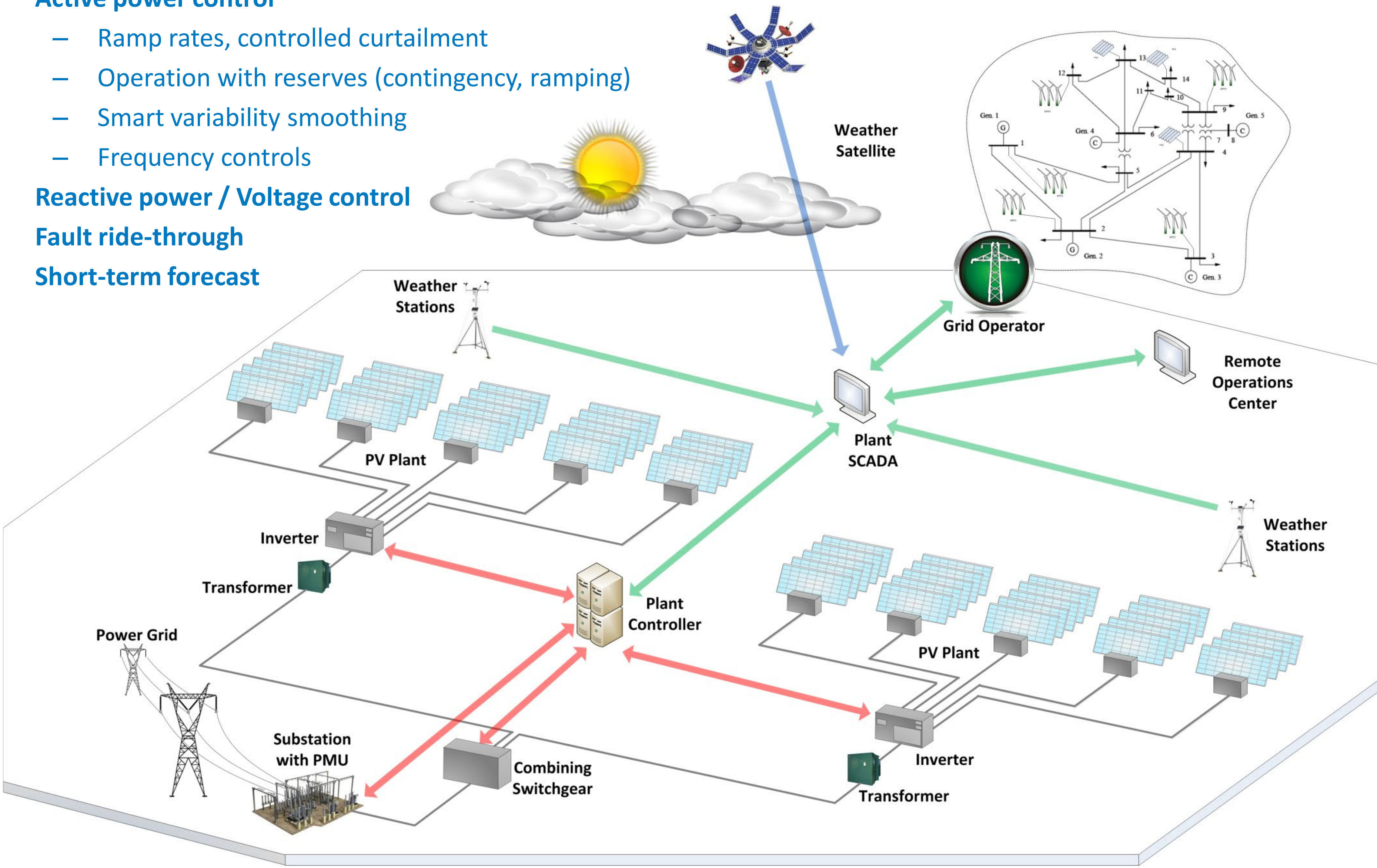
NERC Task Force Recommended Controls

- **Active power control (APC) capabilities include:**
  - Ramp-rate limiting
  - Active power response to bulk power system contingencies
  - Inertial response
  - Primary frequency response
  - Secondary frequency response, or participation in automatic generation control
  - Ability to follow Security Constrained Economic Dispatch (SCED) basepoints that are sent every 5 minutes
- **Performance during and after disturbances**
  - Fault ride-through
  - Short-circuit current contribution
- **Voltage, reactive, power factor control and regulation (both dynamic and steady-state)**

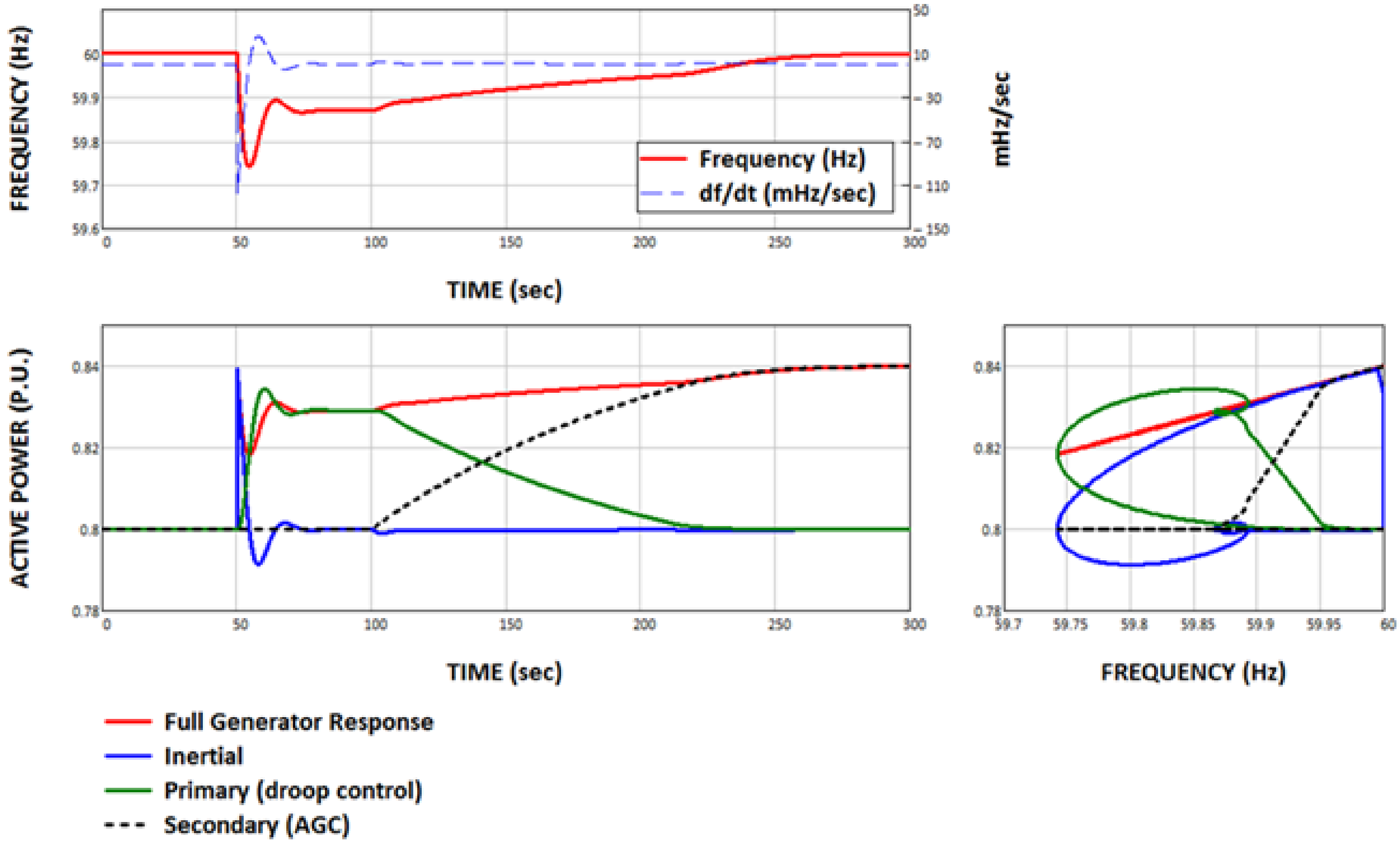


Utility-Scale ‘Smart’ PV Plant Components

- **Active power control**
  - Ramp rates, controlled curtailment
  - Operation with reserves (contingency, ramping)
  - Smart variability smoothing
  - Frequency controls
- **Reactive power / Voltage control**
- **Fault ride-through**
- **Short-term forecast**



FR by Synchronous Generators

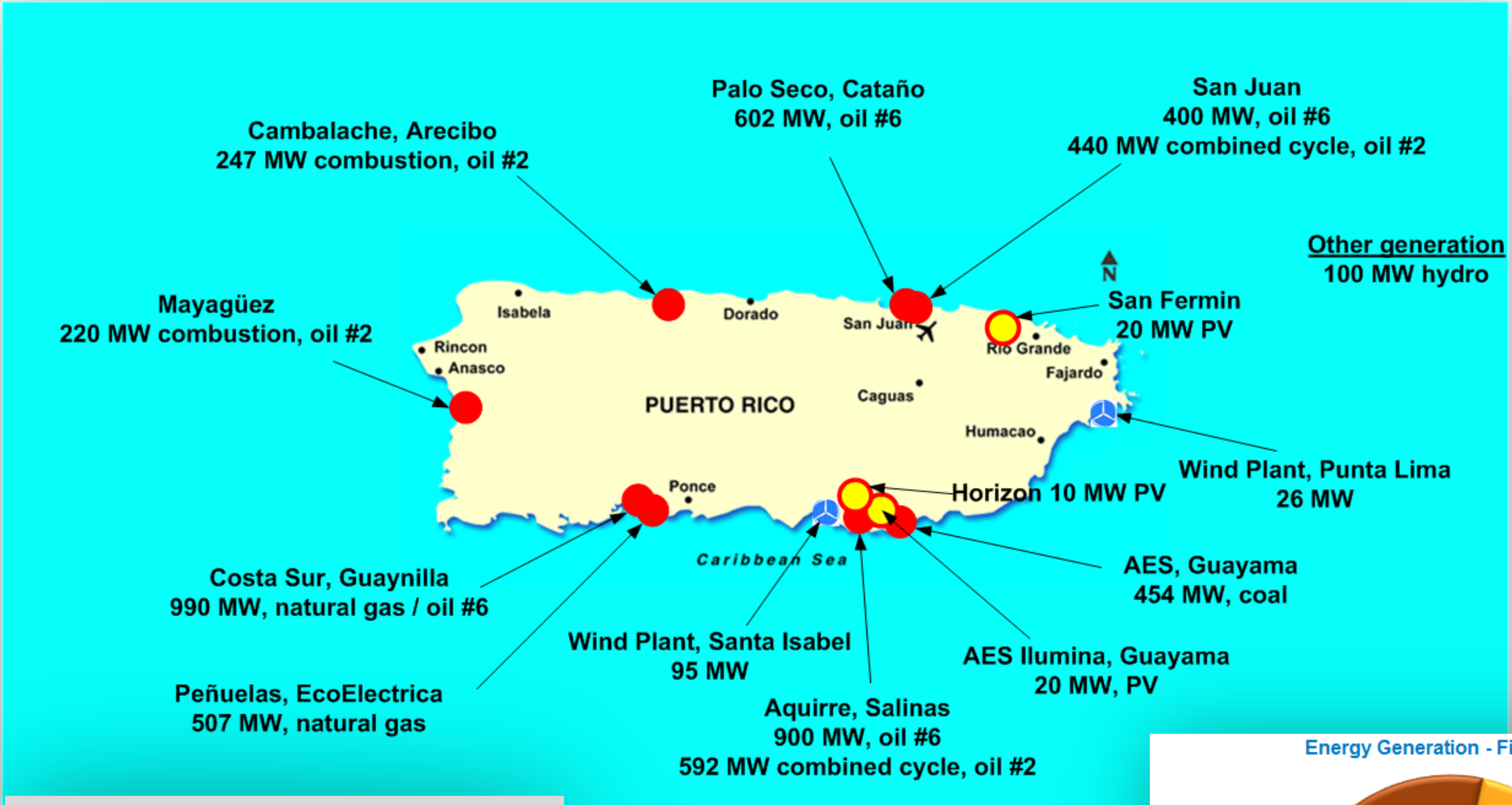


- Can PV generation provide similar FR?
- Can PV generation provide better FR?

Project #1: AES Ilumina in Puerto Rico

- Puerto Rico is in a unique situation in terms of large-scale PV integration
- Higher level of penetration anticipated in future
- Island system, no interconnections
- Reliability impacts are significant
- Operational challenges at any time scale
- PREPA already implemented many PV and wind controls into MTRs, but there are possibilities yet untested
- Use this opportunity to help PREPA address challenges

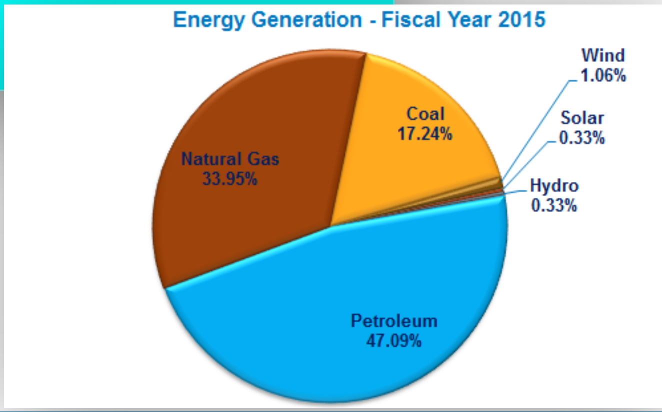
Puerto Rico Generation Capacity



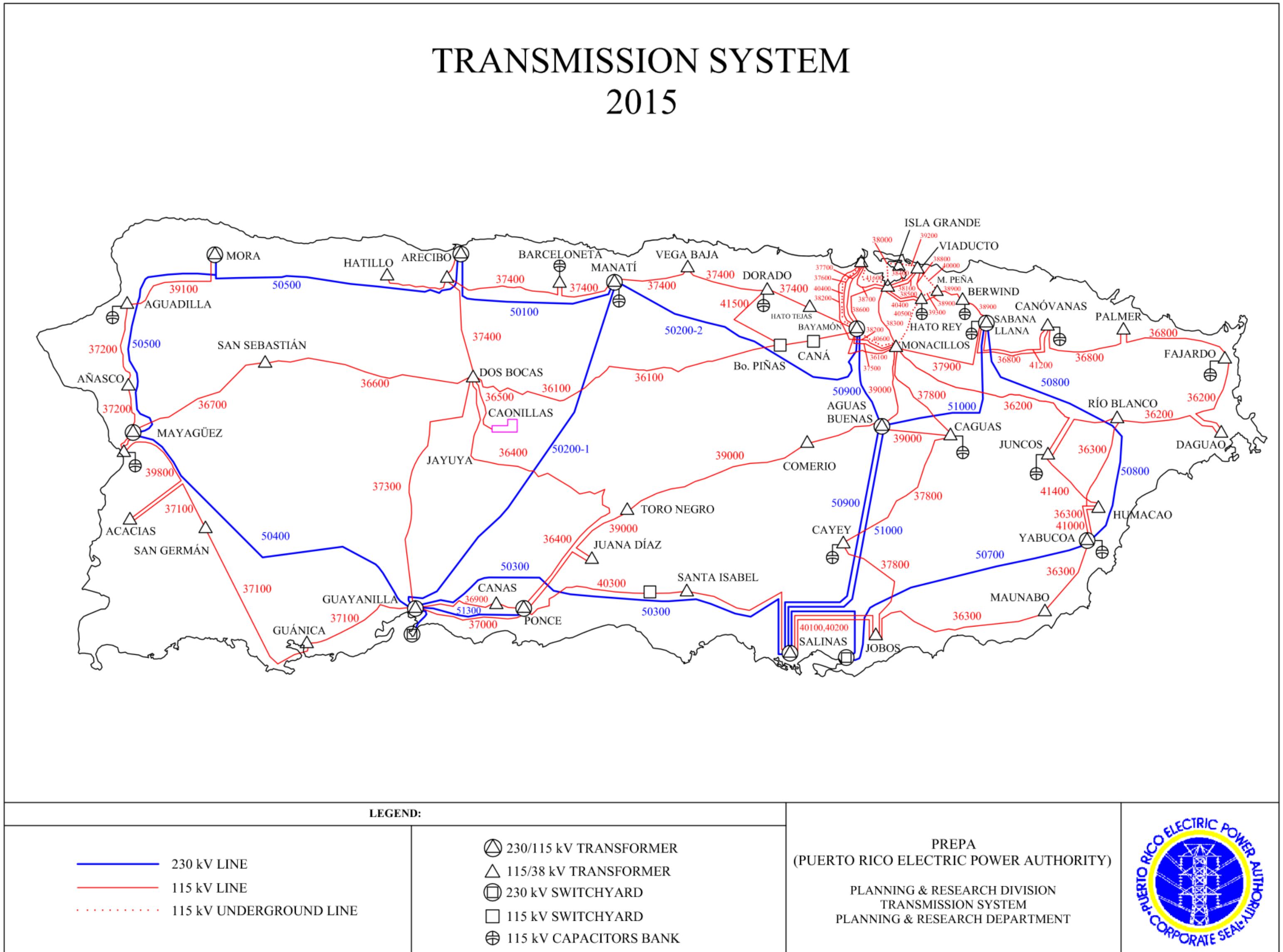
Total installed capacity:

- PREPA – 4,977 MW
- PPOA Coal and NG – 961MW
- PPOA Renewables – 173 MW
- DG and net metering – 70 MW
- *Renewables capacity – 5.8%*

Evening peak: 8-9 pm
2015 peak = 3025 MW



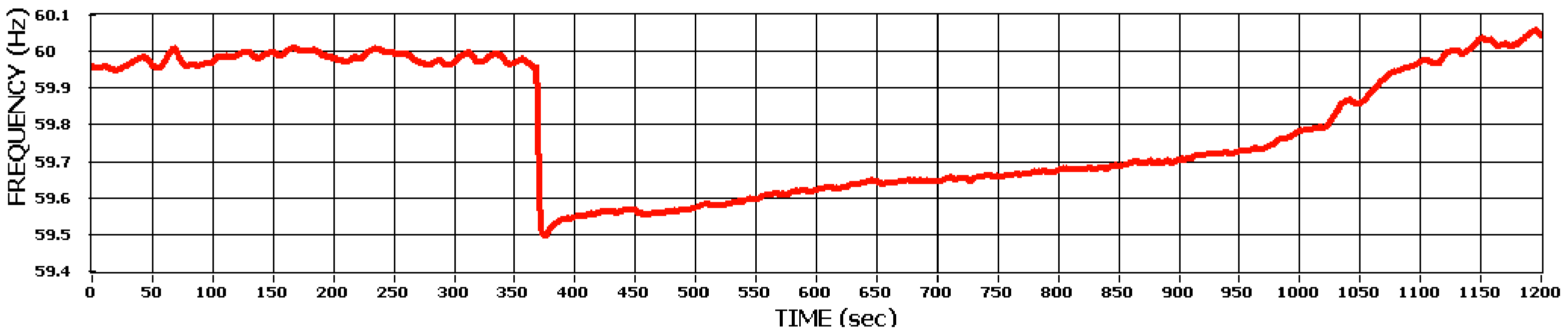
PREPA Transmission System



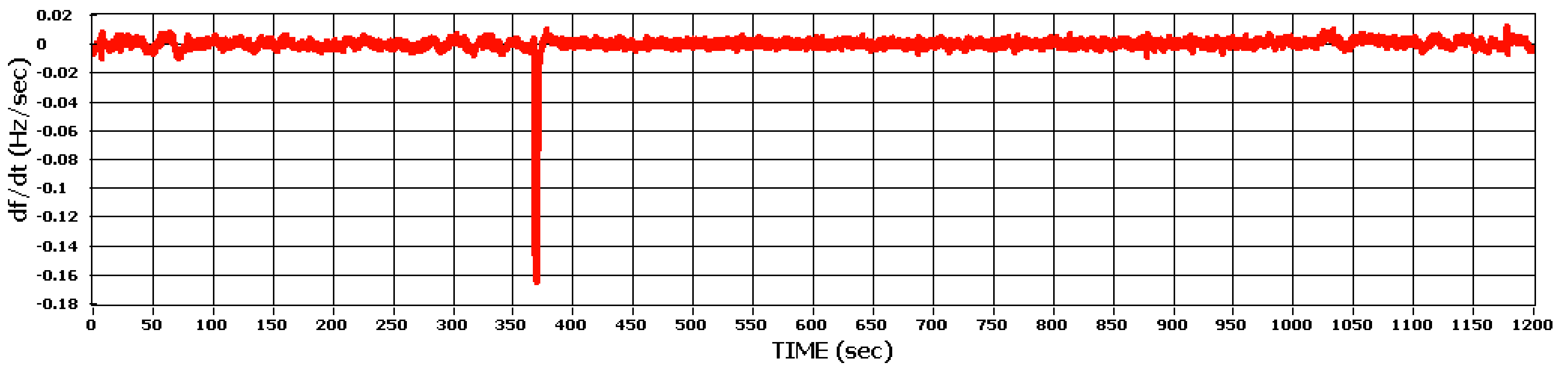
PREPA Frequency Response Example

Nov 22, 2013 – 2:25am

ELECTRICAL FREQUENCY

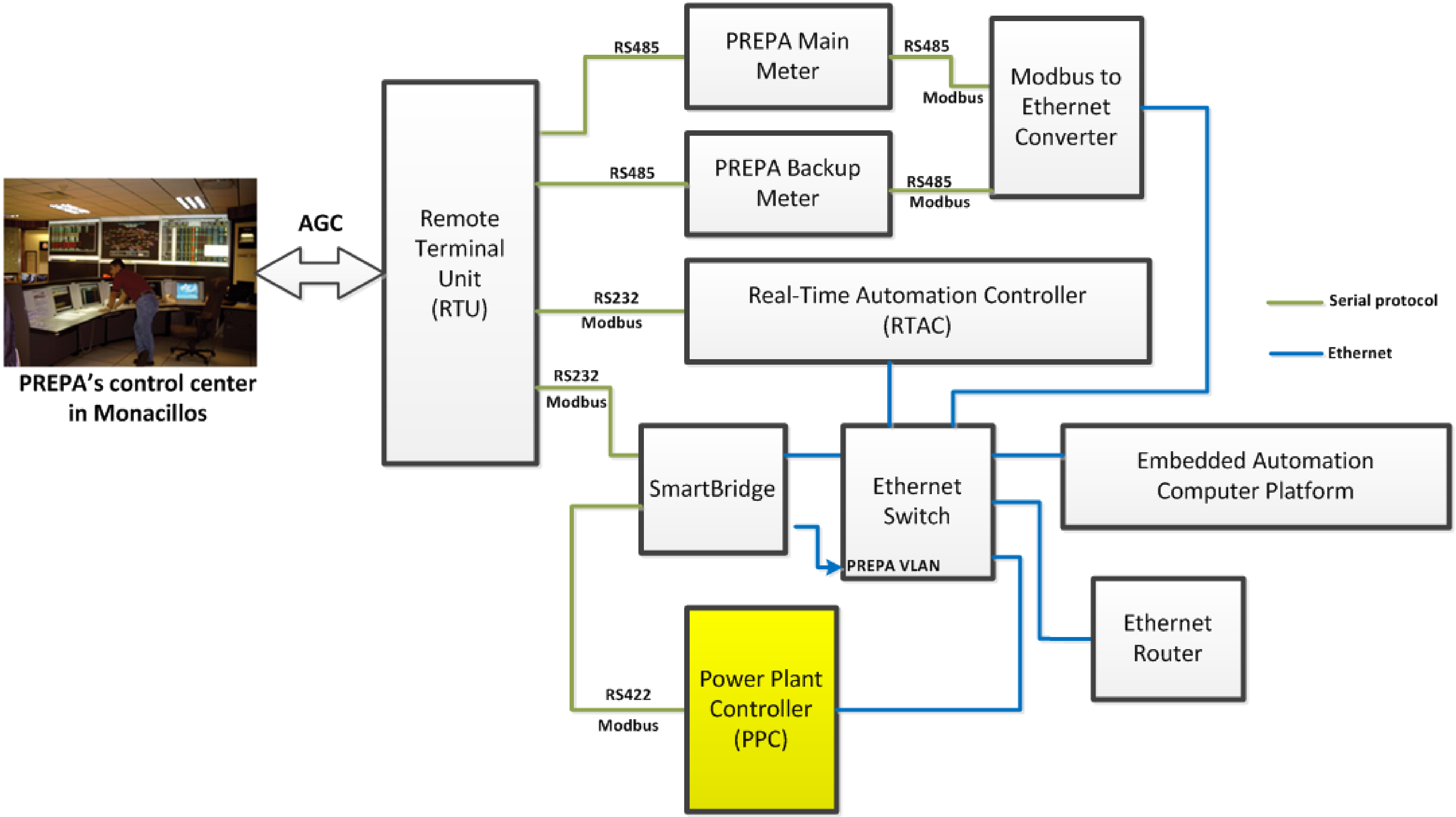


FREQUENCY - RATE OF CHANGE



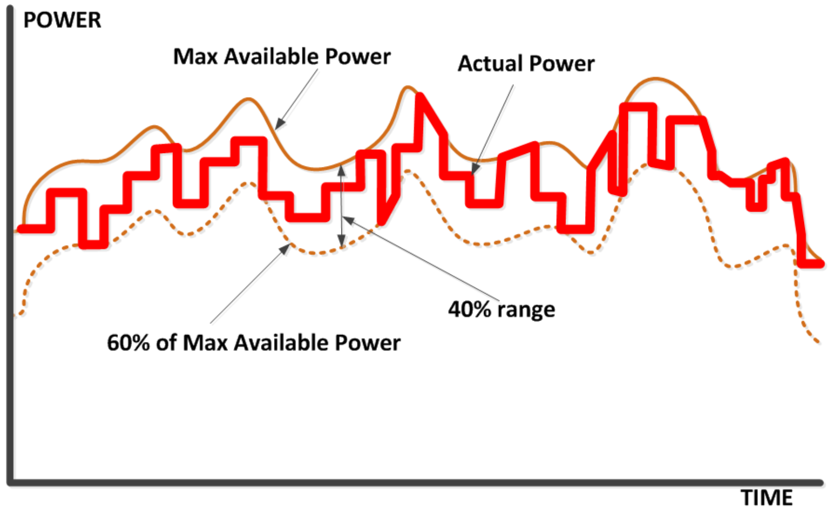
- **Lower inertia compared to large power systems**
- **Limited primary frequency response**
- **Small frequency bias (20 MW/0.1 Hz) implies big impact**

AES Ilumina Communication Diagram

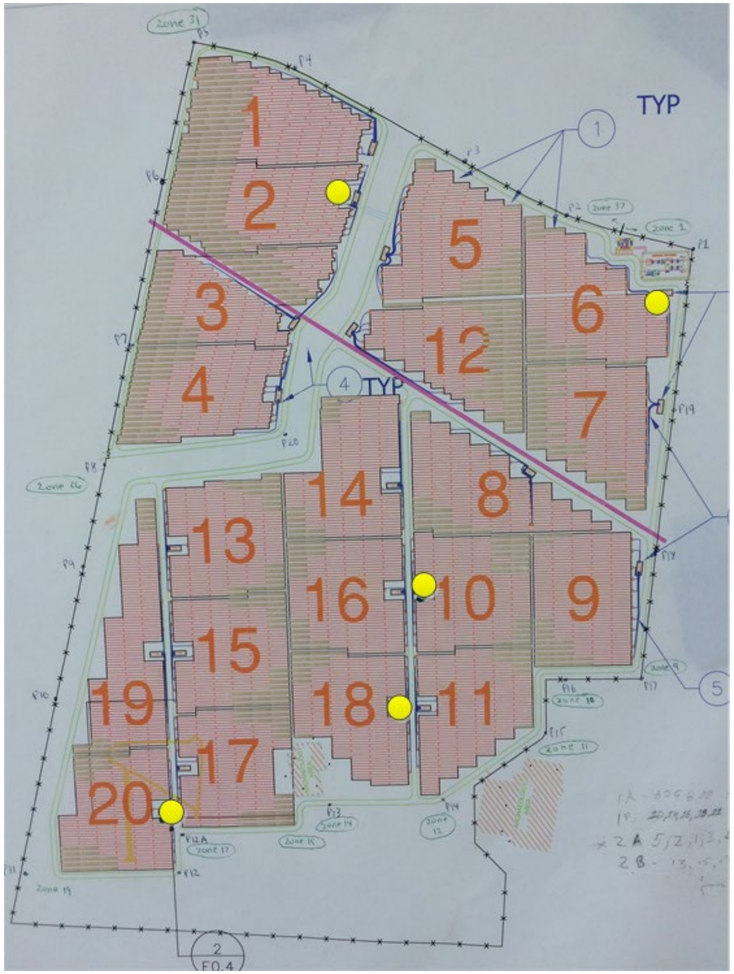


Tests for Ilumina PV plant

- **Plant participation in AGC**
  - Follow PREPA AGC signal within 40% of available power
- **Plant providing frequency droop response**
  - Both up and down-regulation
  - 5% and 3% symmetric droop
- **Fast Frequency Response (FFR) tests**
  - Test plant's ability to deploy all reserve within 500 ms



Available Power Estimation



- **Five control sectors with individual pyranometers**
- **Available power in each sector:**

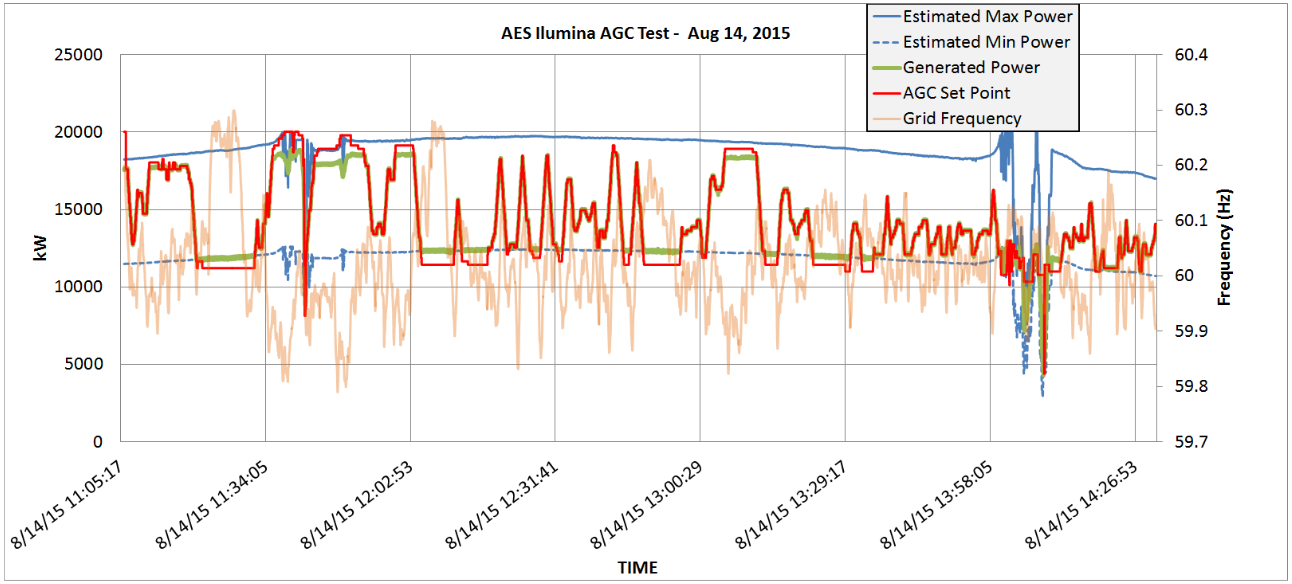
$$P_{sector} = Irr \times Weight_{sector} \times \left(\frac{N_{available}}{N_{total}}\right) \times Scale + Offset$$

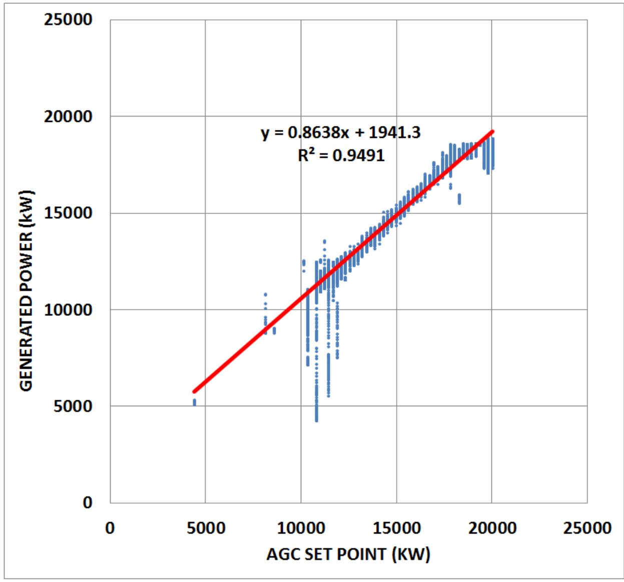
- **Estimated total available plant power:**

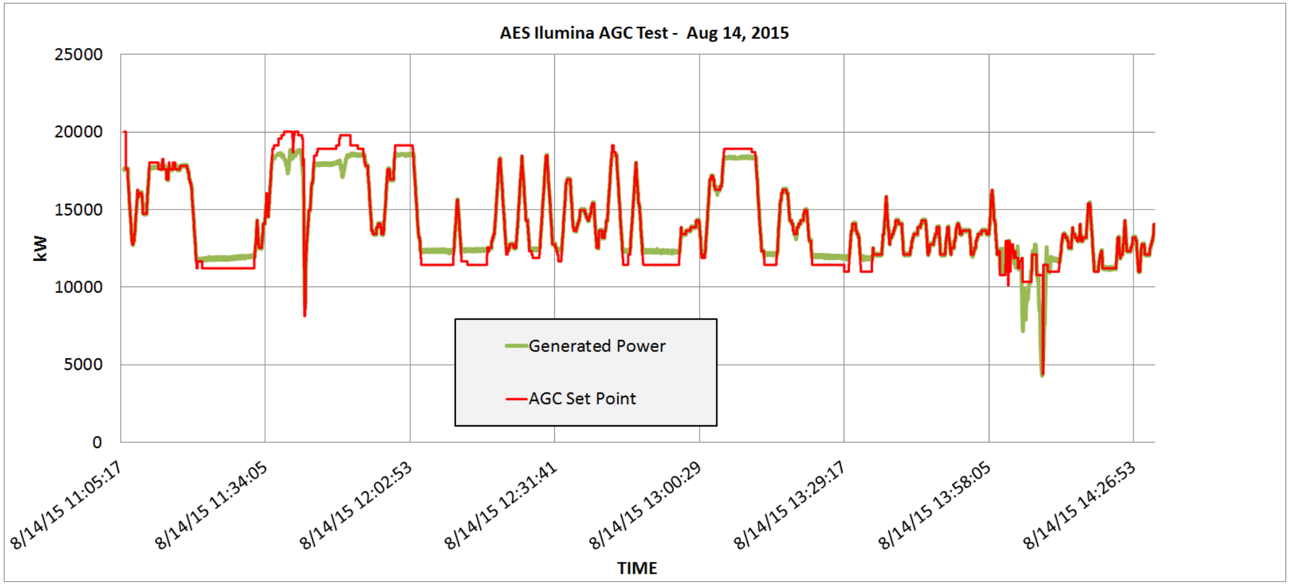
$$P_{plant} = \sum_{k=1}^{5} P_{sector,k}$$

- **Temperatures, inverter efficiency variations, panel soiling not included in the formula (uncertainty source)**

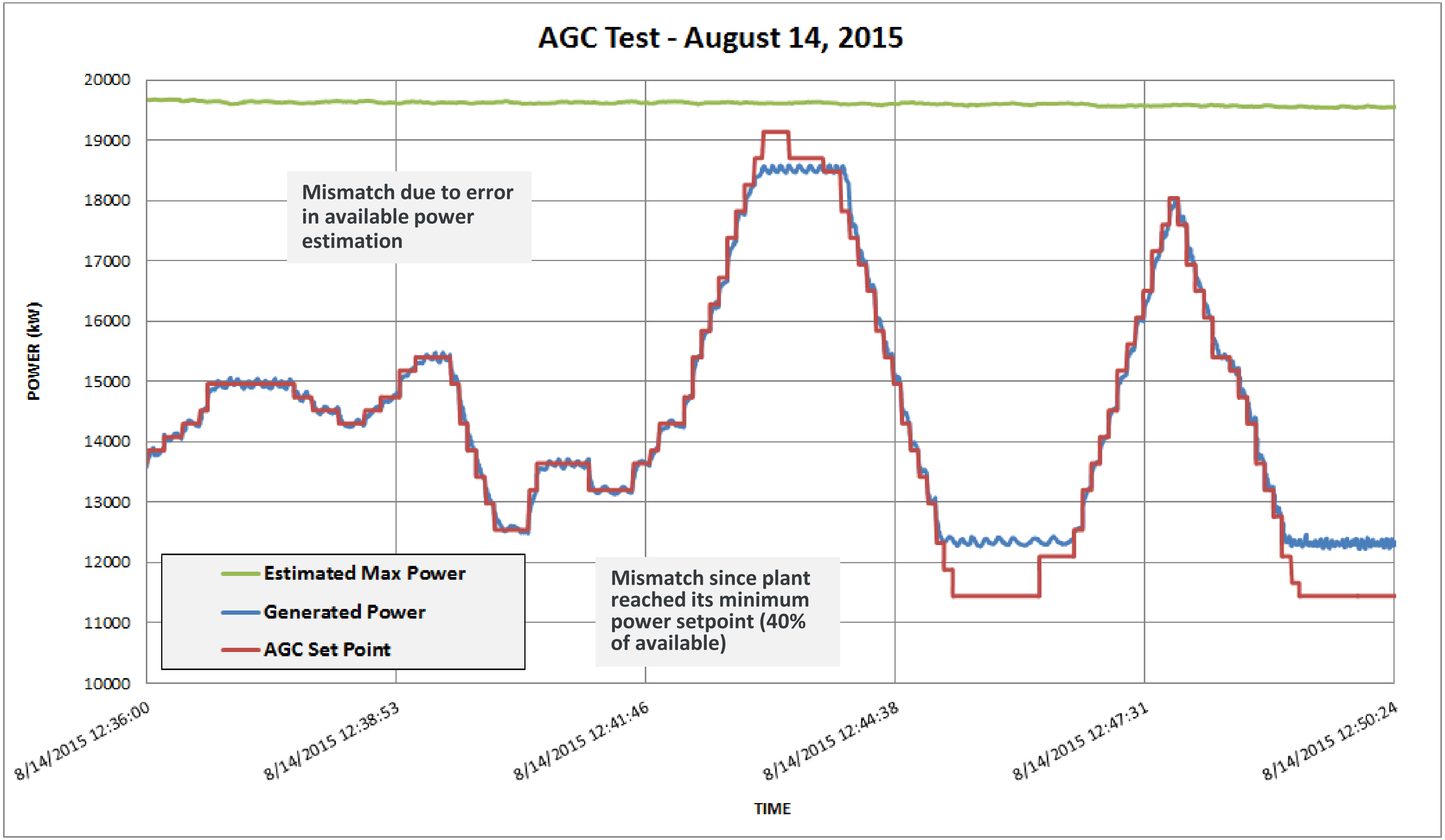
AGC Test – Aug 14, 2015 (40% range)







Plant AGC Performance

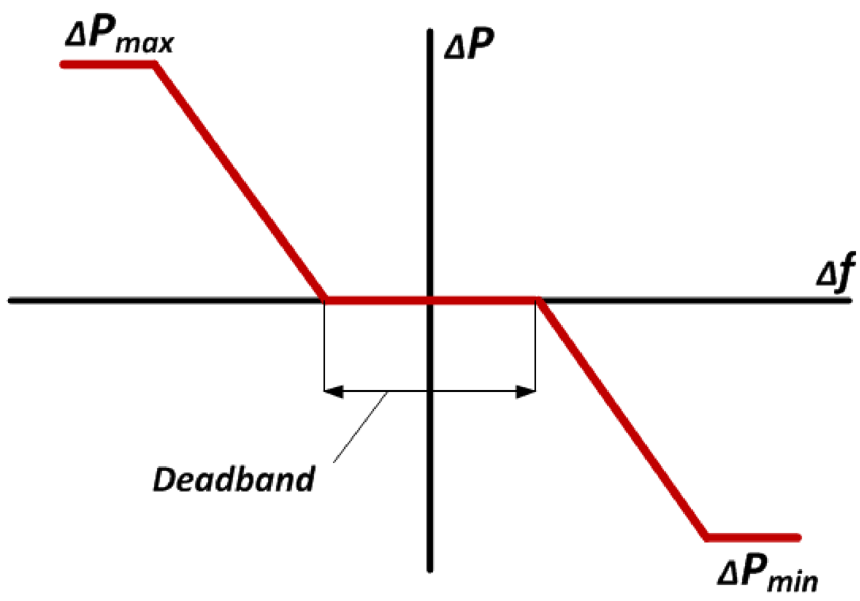


Droop tests

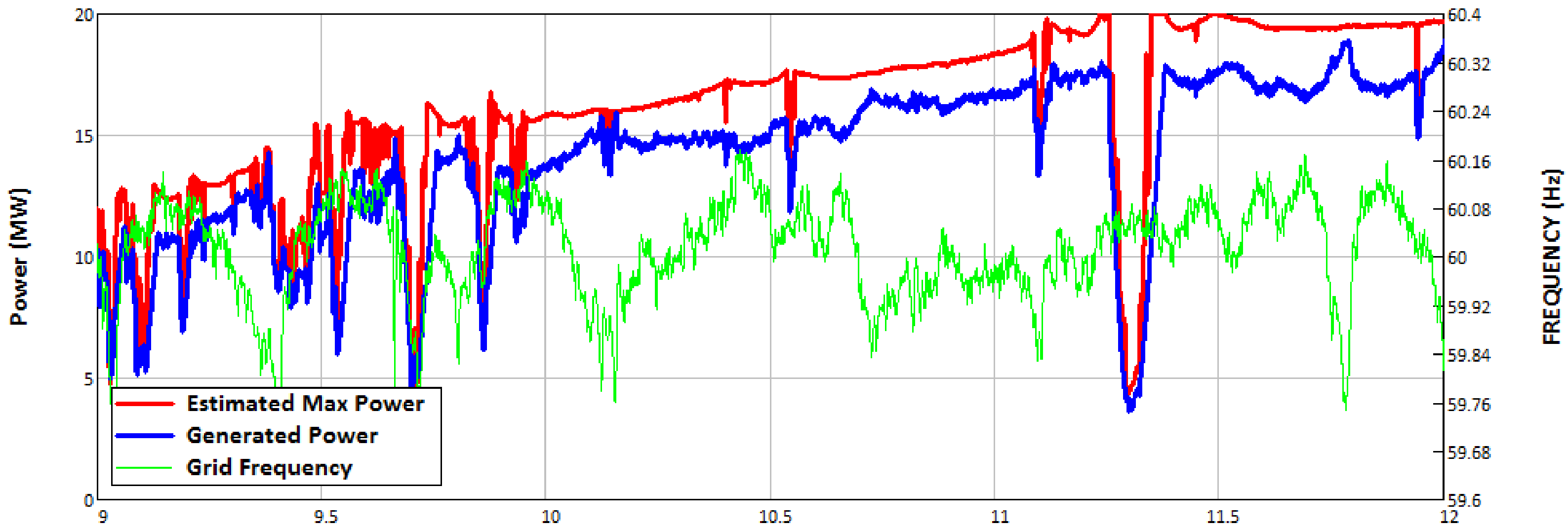
- **Definition of frequency droop**

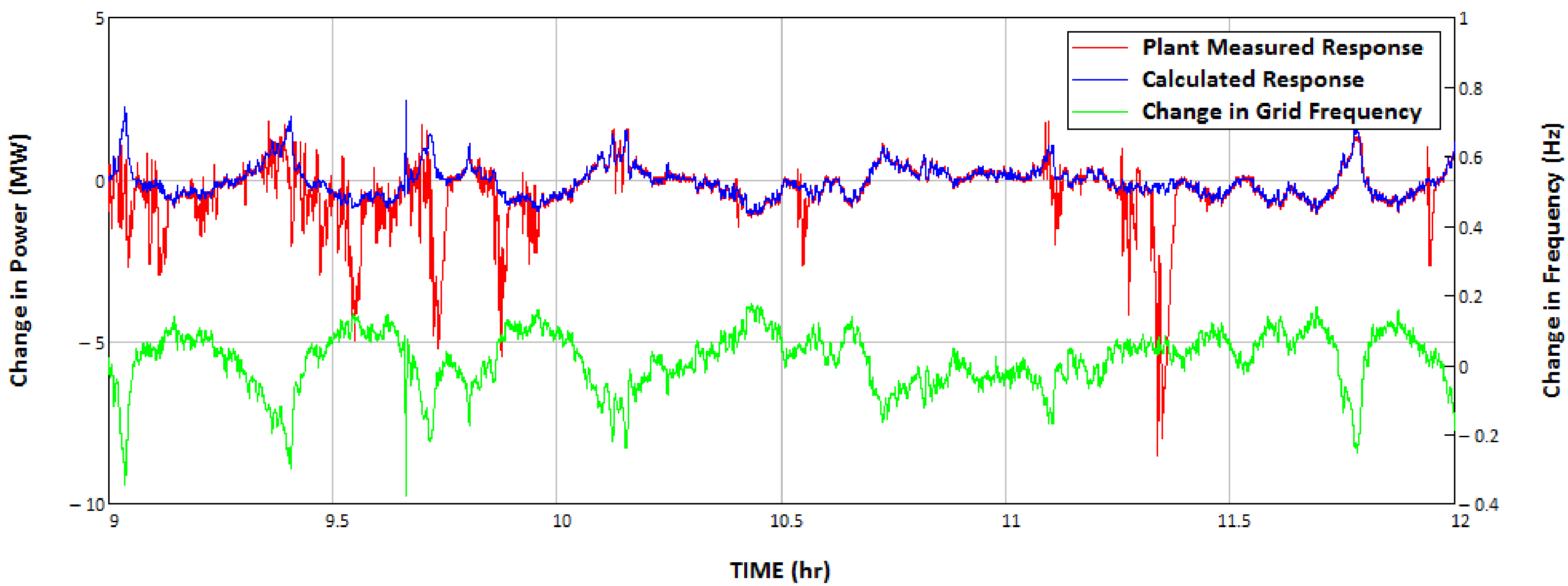
$$\frac{1}{D} = \frac{\Delta f/60Hz}{\Delta P/P_{nom}}$$

- **Plant settings for droop test**
  - 10% curtailment
  - Symmetric droop
  - Upper limit – max power
  - Lower limit – 20% below maximum available
  - Deadband – 25 mHz
  - 5% and 3% droop tests



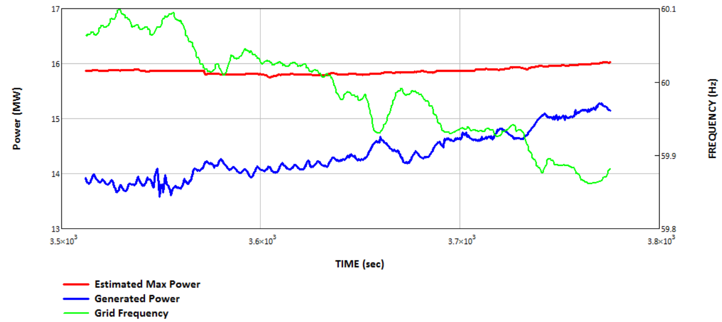
5% droop test – Aug 18, 2015

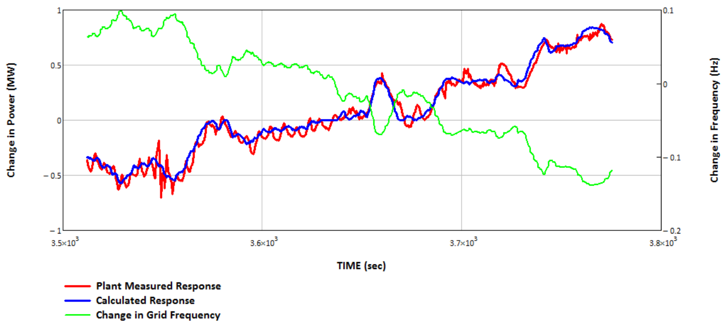


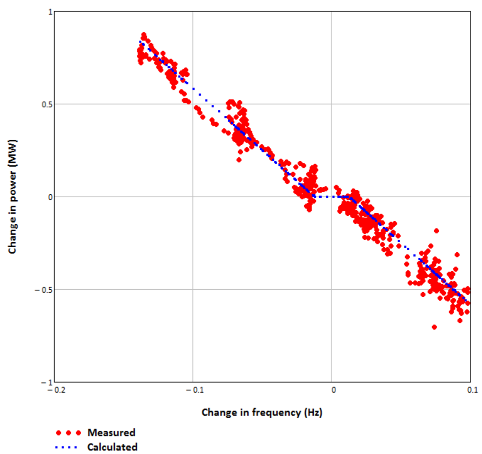


5% droop Test – Aug 18, 2015

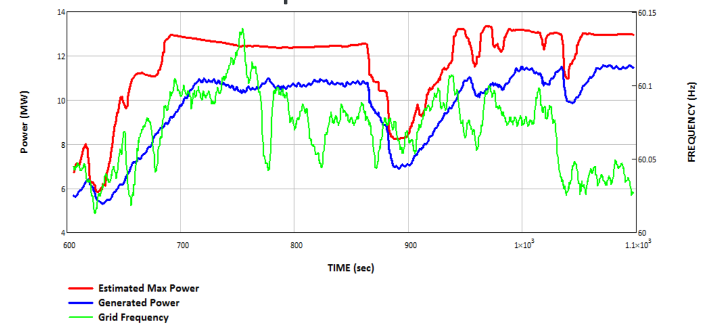
Period of acceptable performance

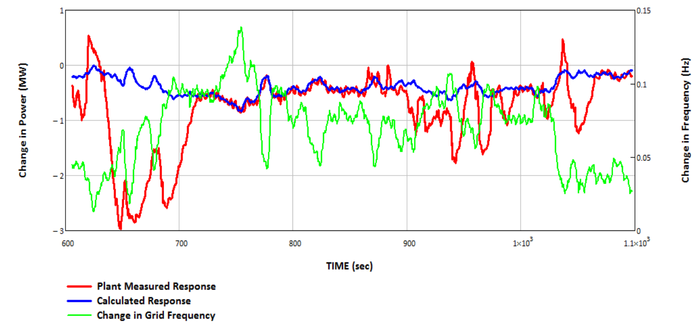


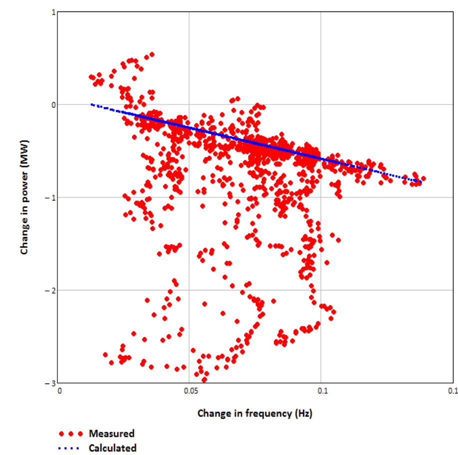




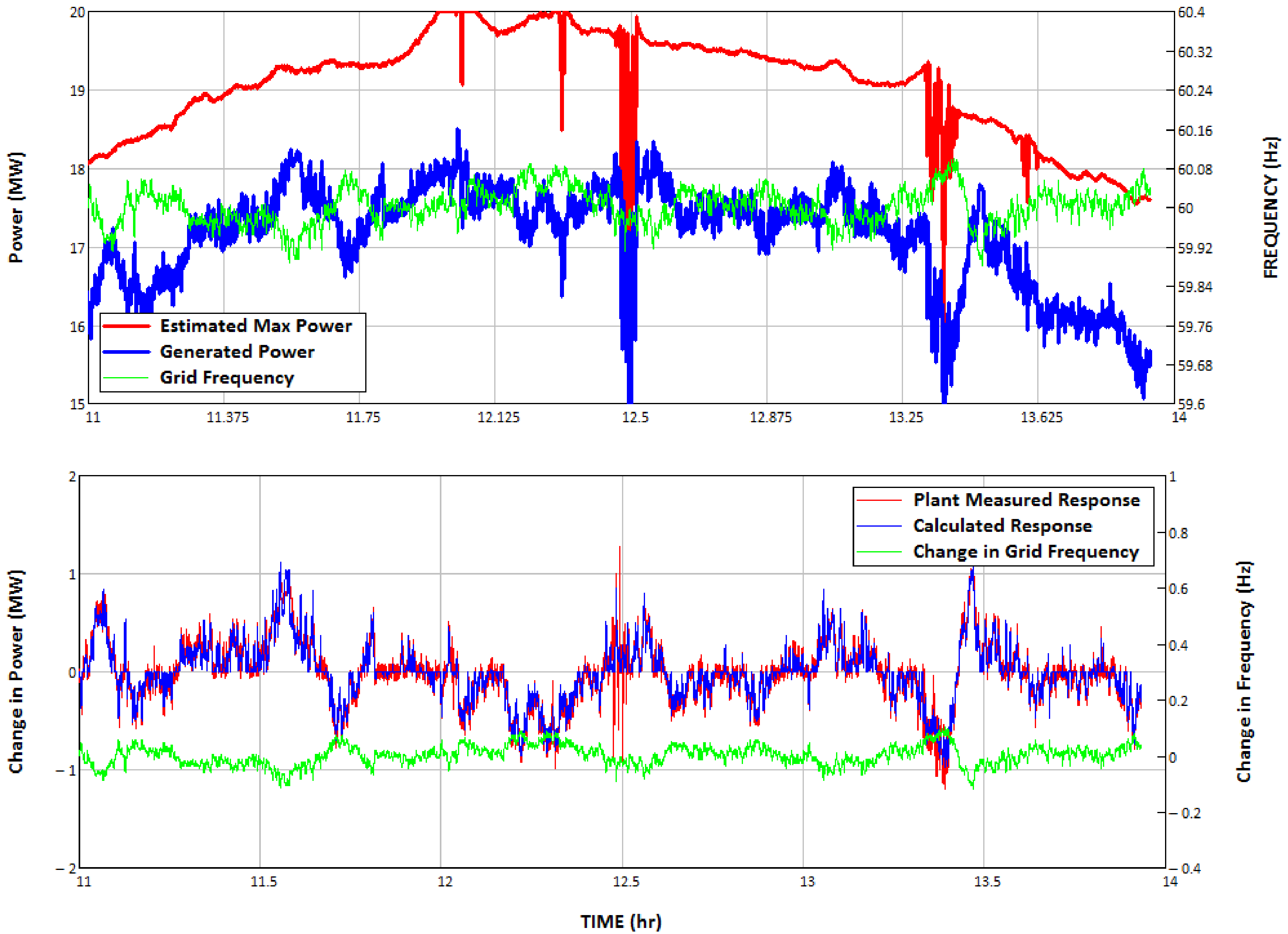
Period of bad droop performance due to active ramp rate limit



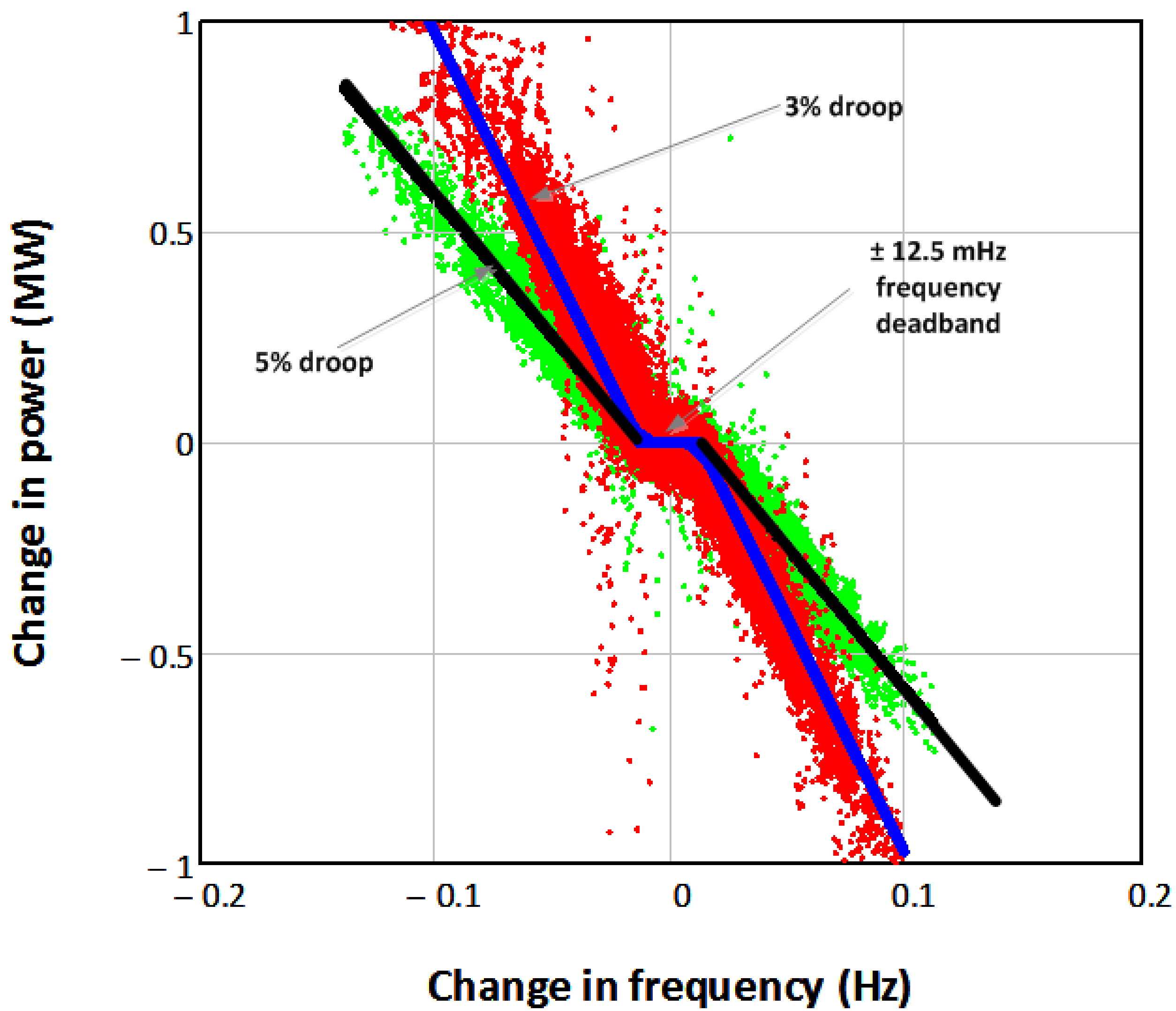




3% droop test – Aug 20, 2015

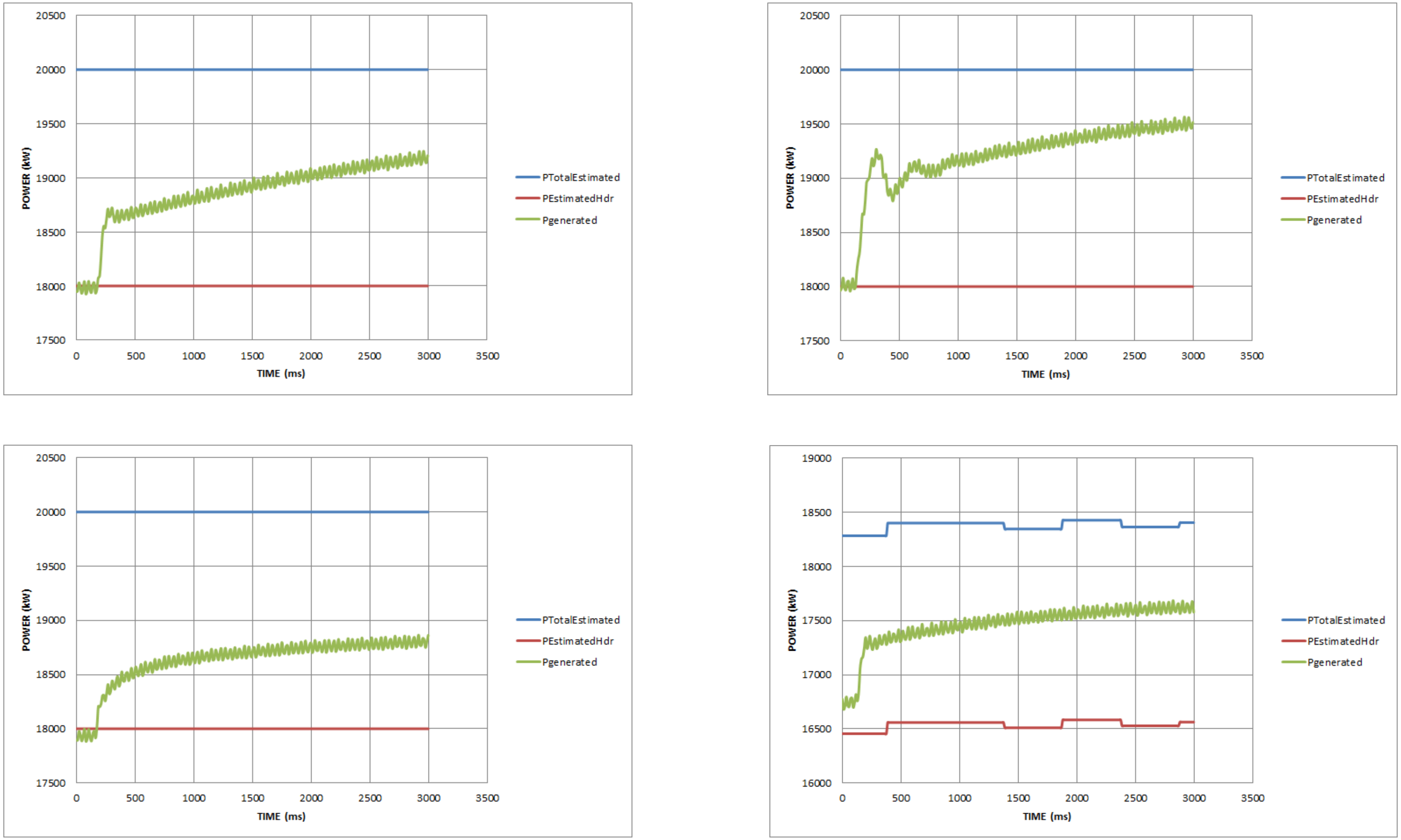


Droop comparison – Aug 19 and 20



FFR Test – High power

Fast deployment of active power reserve demonstrated (within 500 ms)



AES Ilumina Project Summary

- **Three new controls were implemented and demonstrated on AES Ilumina 20 MW PV plant**
- **AGC tests**
  - 4 days of testing
  - Around 15 hrs in AGC mode at peak production hours (10-11am … 2-3pm)
  - Fast and accurate AGC performance demonstrated
- **FFR test**
  - Fast performance demonstrated
  - More control tune-ups might be necessary in future
- **3% and 5% droop tests**
  - Fast and accurate droop performance during low variability
  - More scattered performance during fast solar ramps

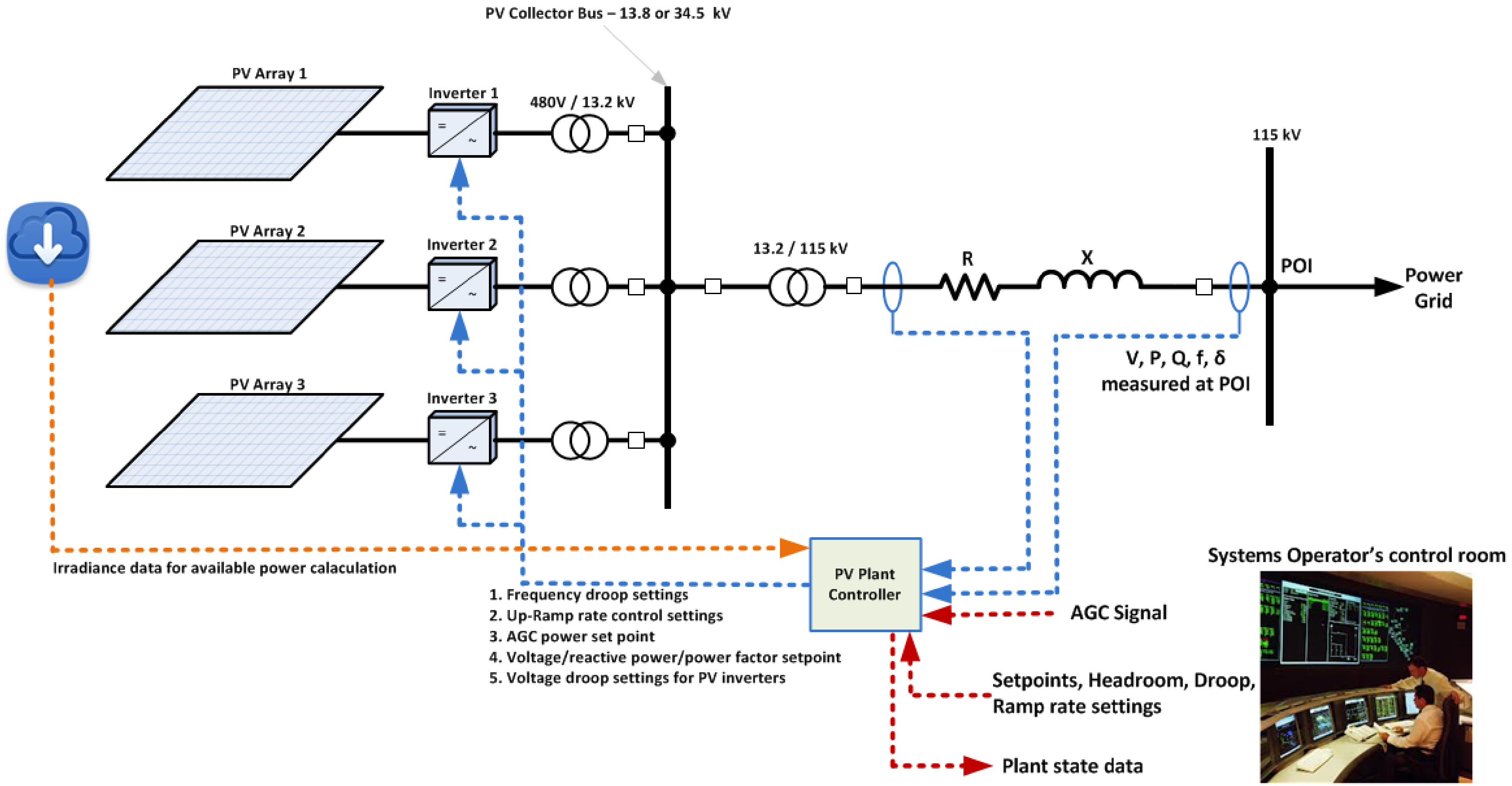
AES Ilumina Project Conclusions

- Accurate estimation of available peak power is important for precision of AGC control
- Makes sense to include specifications for such estimation into interconnection requirements (lesser problem for plants with energy storage)
- System level modeling exercise will be needed to determine exact parameters of each control feature for maximizing reliability benefits

NREL/DOE thanks PREPA and AES teams for their assistance and valuable contributions into this work !!!

General Conclusions

- Hardware components enabling PV plants to provide full suite of grid friendly controls are already in existence in many utility-scale plants
- Mainly a matter of controls and communications upgrades to fully enable these capabilities



General Conclusions (cont'd)

- Many utility-scale PV plants are already capable of receiving curtailment signal from grid operator; each plant is different but it is expected to be a relatively simple transition to AGC operation mode with just a plant controller and interface software modification
- Fast response by PV inverters makes it possible to develop other advanced controls, such as power oscillation damping
- PV plants without energy storage are capable of providing many services to the grid but market mechanisms and/or new interconnection requirements are needed to incentivize curtailed operation for any up-regulation service