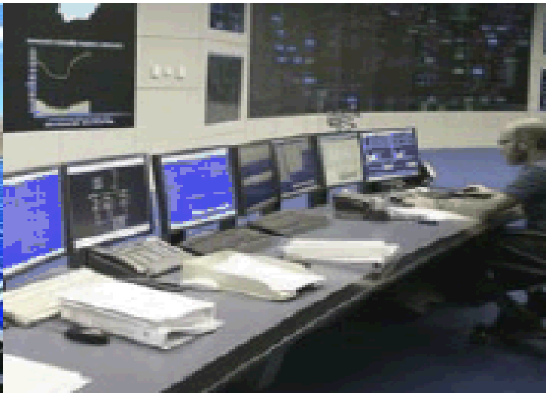
SAND2013-4327C

Sandia National Laboratories



PV Output Smoothing using a Battery and Natural Gas Engine-Generator

Acknowledgments of Support to:
DOE - Office of Electricity
Dr. Imre Gyuk Electricity Storage Program Manager

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Albuquerque, NM

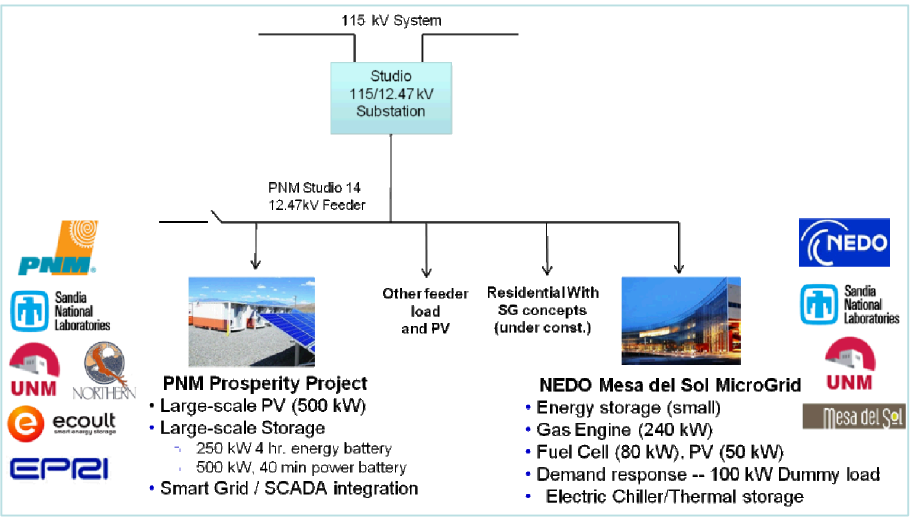
U.S. DEPARTMENT OF ENERGY

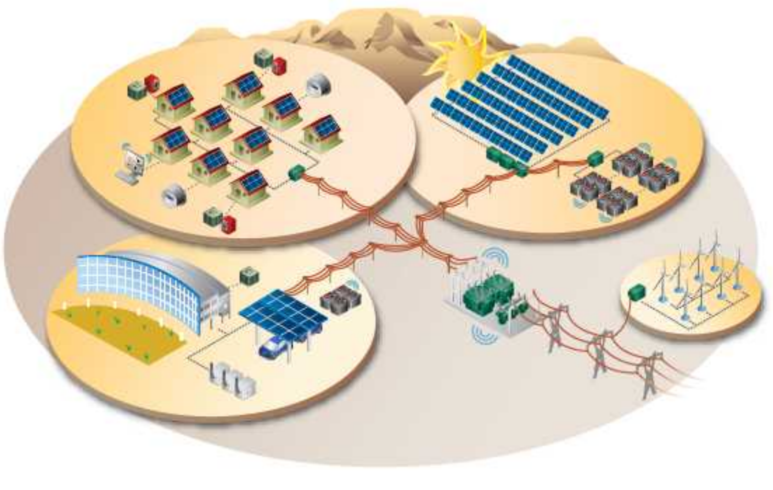
NNSA National Nuclear Security Administration

Background on Research Project

Sandia National Laboratories

- Demonstrate joint operation of the PNM Prosperity Facility and NEDO Microgrid at Mesa Del Sol with distributed, coordinated control
  - Start analysis of Gas Engine – Battery operation for PV output smoothing
  - Controls optimization and plan for future field demonstration
  - Part of a larger PNM vision of renewables and smart grid integration



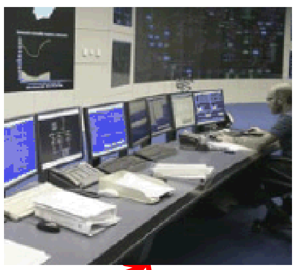


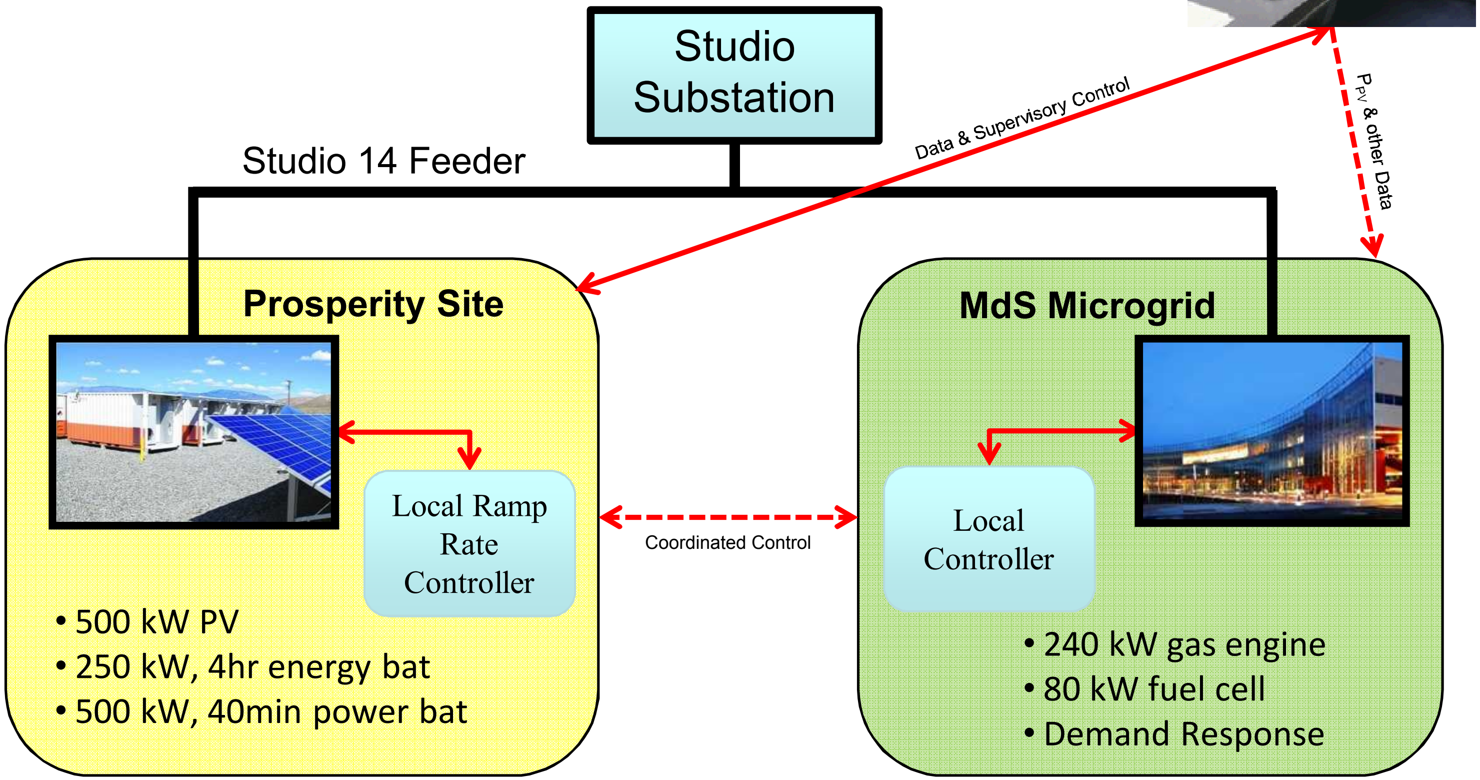
- The project involving Sandia, PNM, UNM, MdS, Tokyo Gas and Shimizu
- Sandia's effort is sponsored in part by DOE Energy Storage Program


Albuquerque
I-25
Albuquerque Airport
Kirtland Air Force Base
I-25
Mesa del Sol
PNM Prosperity Project
- 500 kW PV
- 500 kW, 330 kWh Smoothing Battery
NEDO Mesa del Sol Aperture Center
- 240 kW Natural Gas Engine-Generator

Coordinated Controls

- Data flow the two sites is currently one-way
  - Existing Prosperity PV smoothing control does not take into account MdS gas engine and fuel cell output
  - Evaluated coordinated control with communications (optimal) and without

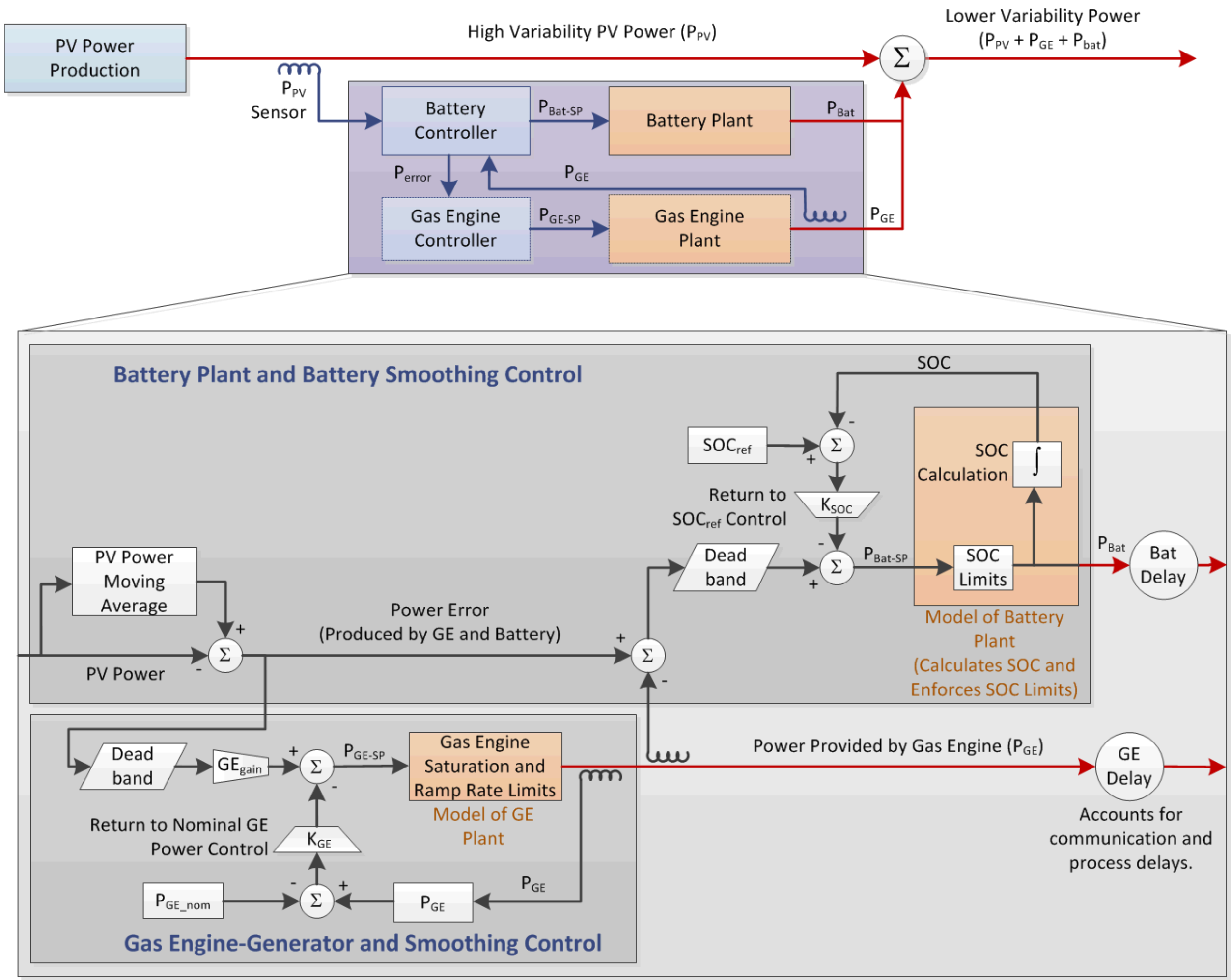


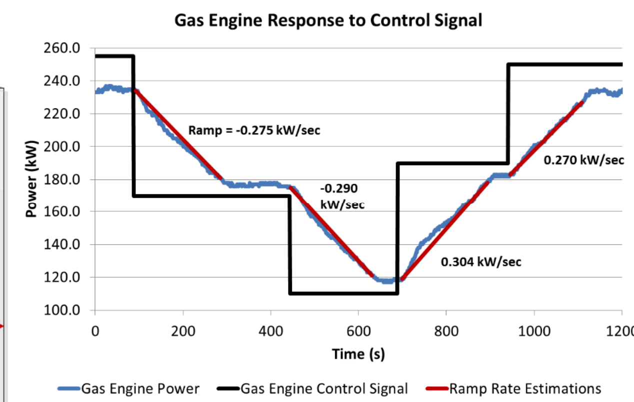


Control Algorithm Design

- Existing controls
  - Local PV smoothing control implemented at Prosperity
- Extended objective: Demonstrate by simulation coordinated operation of Prosperity battery and MdS gas engine to smooth PV plant output
  - P_{bat} and P_{GE} are controlled to minimize $P_{smooth} – P_{pv}$
  - P_{smooth} is computed by applying a moving average of P_{pv}
  - Simple proportional control with deadband, rate limits, and saturation
- Sub-objectives
  - Maintain battery SOC within a prescribed range
  - GE output and battery SOC should recover to a *target level* to avoid saturation (for example, battery SOC = 0.5±0.2 per unit; GE output is 180±60 kW)
  - Optimize according to several possible figures of merit (for example, battery SOC swings or amount of ampere-hour processed)

Control Structure with Communication

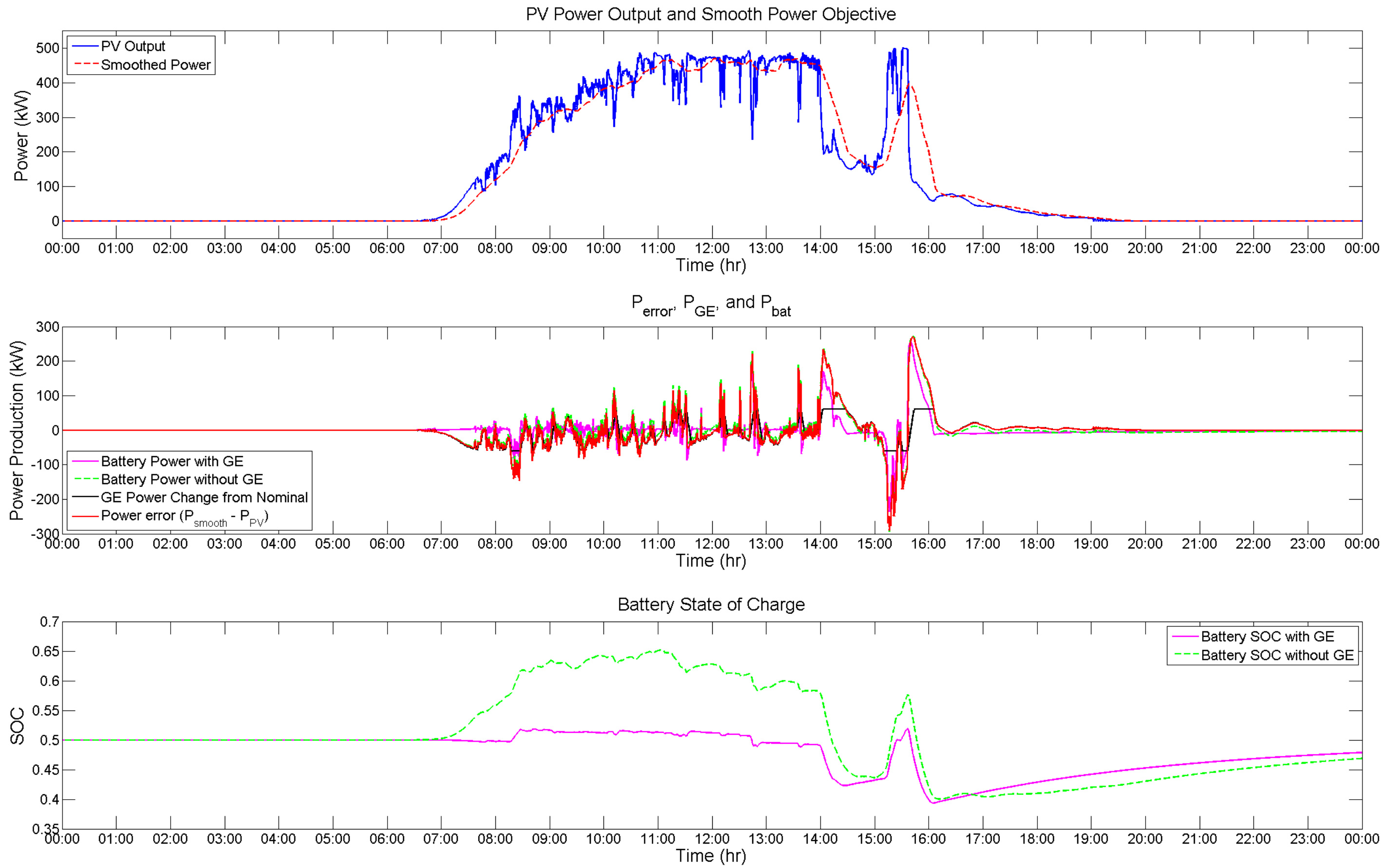




Parameter	Default Value	Range of Values
GE_{gain}	1	0-1
T_w	300 s	300-1800 s
K_{SOC}	100	10-1000
K_{GE}	$0.2*GE_{RRSat}$	$0.05*GE_{RRSat}$- $0.5*GE_{RRSat}$
GE Delay	0 s	0-5 s

Joint Operation During an Example Day

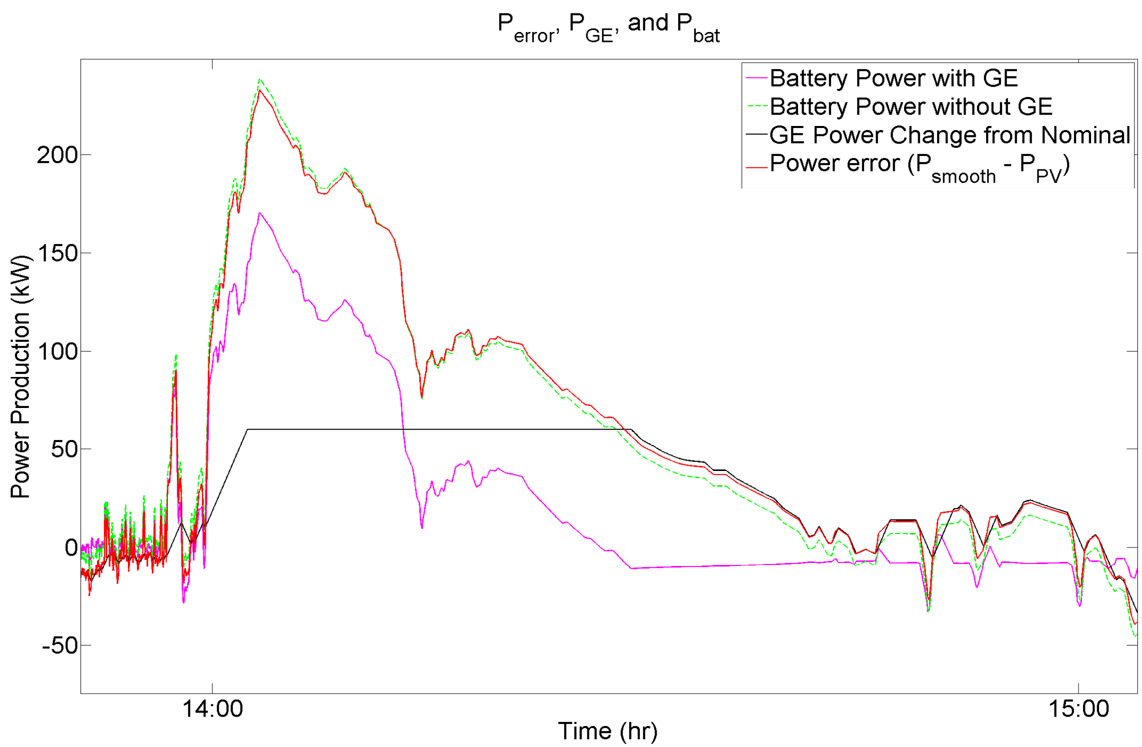
- Same smoothing performance, but much smaller battery SOC swing



NOTE: For ease of comparison, the target level of P_{GE} (180 kW) was subtracted

Joint Operation During an Example Day

- The gas engine is slow; battery must respond initially to fast ramps
- However, the gas engine reduces the amount of power from the battery during sustained excursions



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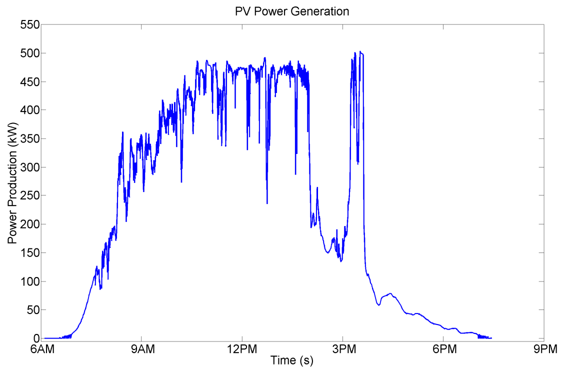
Optimization Against Figures of Merit

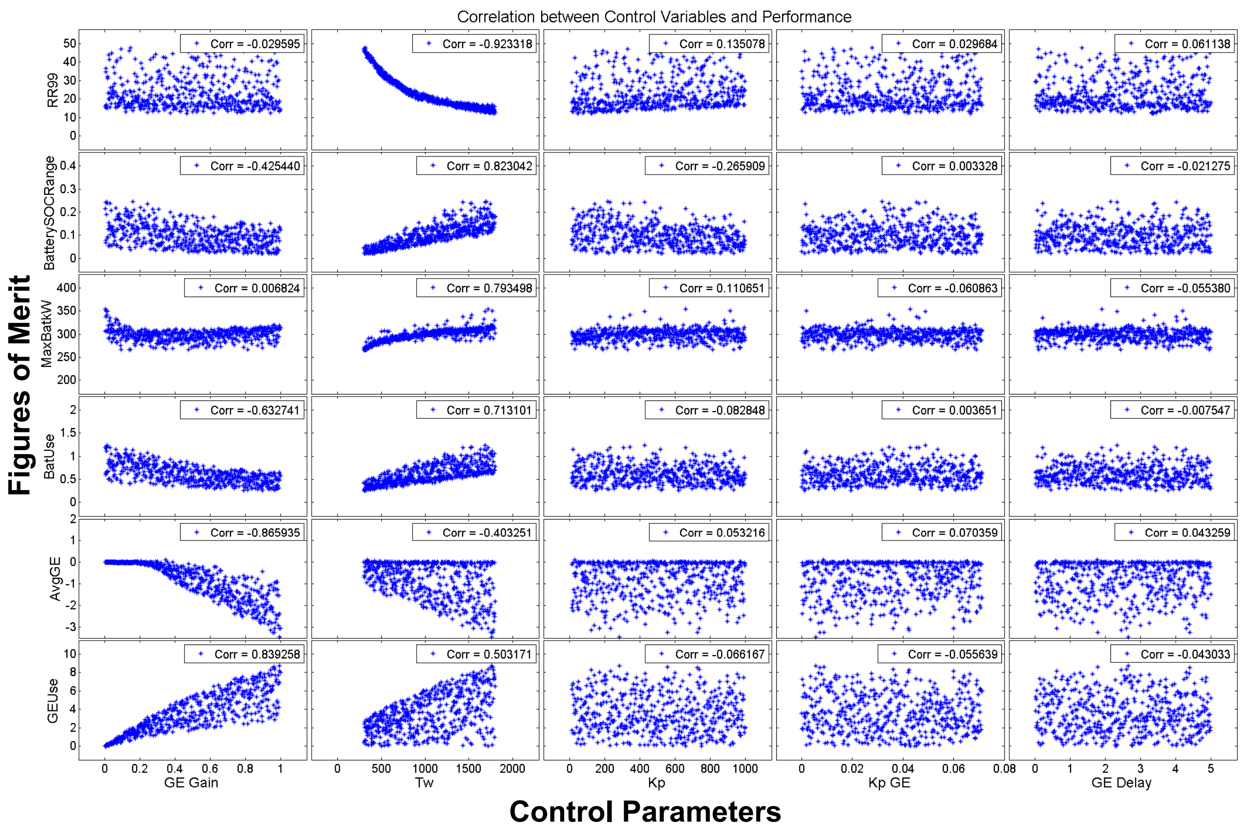
- **RR_{99}** = The 1-minute ramp rate in kW/min at the 99th percentile of the CDF. This is a good approximation of the performance of control system.
- **BatSOCRange** = This is the range of battery power that was used for the simulation. This is used to predict the required capacity of the battery.
- **MaxBatkW** = The maximum instantaneous output power of the battery during the simulation. This defines the size of the battery and the inverter connected to the battery.
- **BatWork** = Total work done by the battery during the simulation, in GWh (surrogate to amp-hours assuming constant voltage), as defined by: $\int |P_{Bat}| dt$. This is related to the lifetime of the battery.
- **AvgGEpower** = The average gas engine power production in kW (referenced from the target level), indicating the amount of additional fuel that the GE uses, ignoring fuel efficiency and acceleration.
- **GEwear** = The amount of GE adjustment during the simulation, $\int |P_{GE}| dt$.

Optimization Against Figures of Merit

- Latin Hypercube technique was used to understand the effect of each control variable on the Figures of Merit
  - Key parameters are K_{GE} and T_w. The rest of the parameters have little impact



Day 1 Test Day



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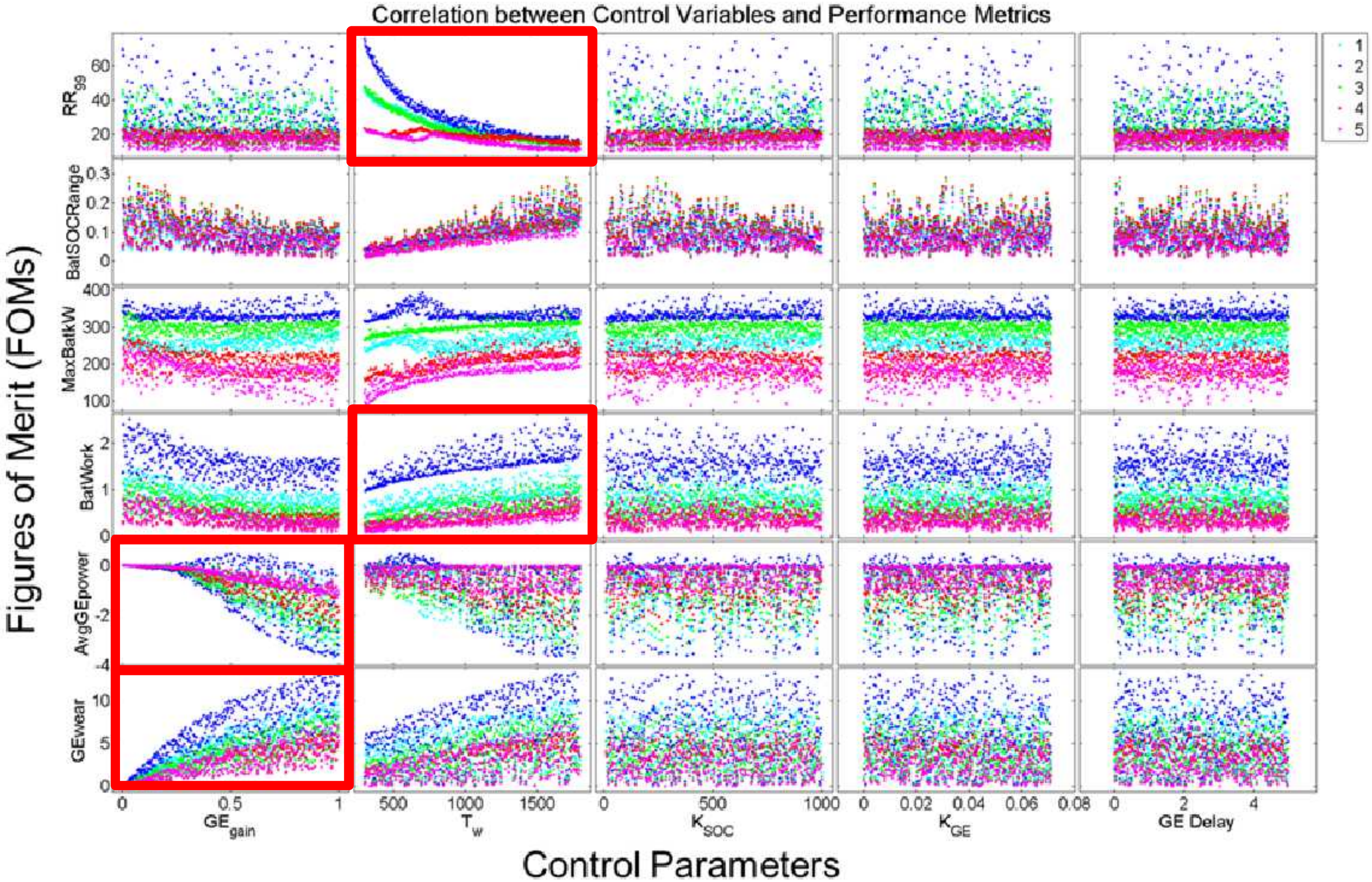
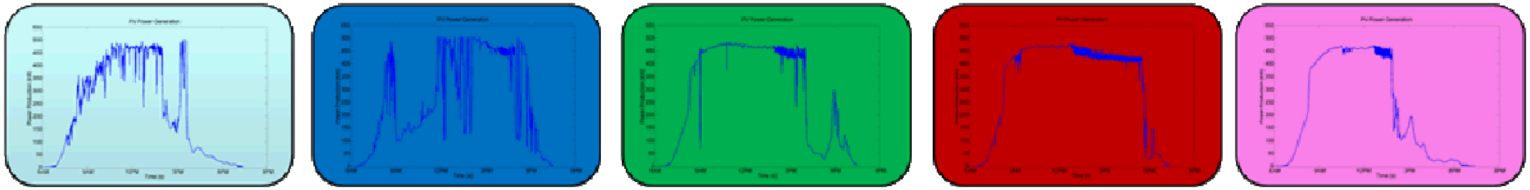
GE Delay	0 s	0-5 s

Correlations for Different Test Days





Example of Optimization

- Consider a situation where PV ramp rates must be kept below 50 kW/min. The system owner is interested in minimizing the battery size and ensuring reasonably long battery operating life. What would be the optimal control parameters?
  - A simple optimization problem could be setup as follows

$$F_i = K_{RR,i} \cdot \left[f(BatSOCRange_i) + f(BatWork_i) \right]$$

$$K_{RR,i} = \begin{cases} 1 & \text{if } RR_{99,i} < 50\, kW/\min \\ 0 & \text{if } RR_{99,i} > 50\, kW/\min \end{cases}$$

$$f(BatSOCRange_i) = w_1 \left(\frac{\max(BatSOCRange) - BatSOCRange_i}{\max(BatSOCRange)} \right)$$

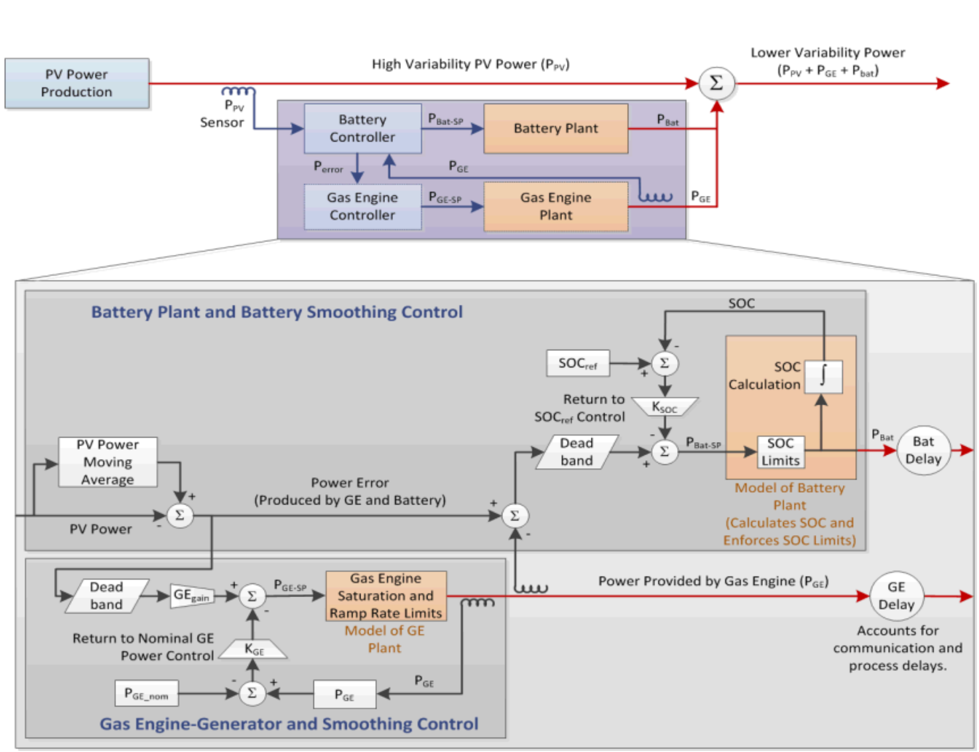
$$f(BatWork_i) = w_2 \left(\frac{\max(BatWork) - BatWork_i}{\max(BatWork)} \right)$$

  - Optimal parameters: T_w = 445, GE_{gain} = 0.53, and K_{SOC} = 10.0

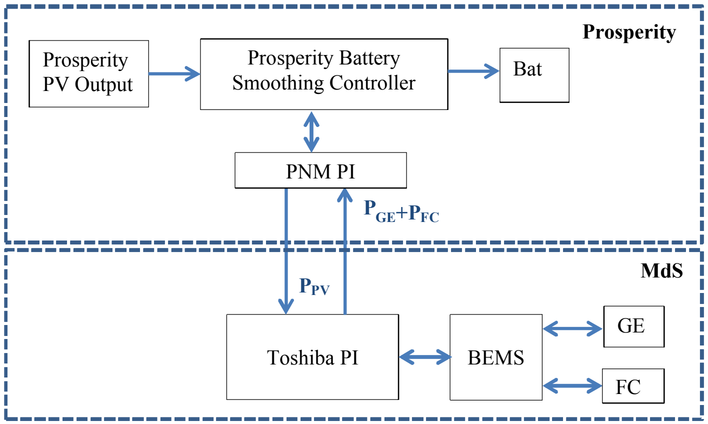
Coordinated vs. Independent Control Test Plan Summer 2013

Test A: Real-time demonstration of coordinated control

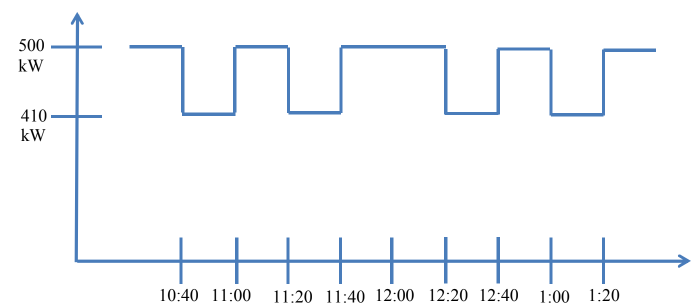
- PV output smoothing using the Prosperity battery with assistance from a gas engine-generator and fuel cell (coordinated control with a PI-to-PI link between prosperity and MdS).
- PV output smoothing using the Prosperity battery with assistance from a gas engine-generator and fuel cell (no coordination between prosperity and MdS).



Coordinated Control



PI-to-PI Interface



Step Changes from Physical Switching

Conclusions

- Collaboration was successful and key objectives were met
  - Validation of models for GE/battery and smoothing controls
  - Evaluation of control performance against different Figures of Merit
    - Basis for control optimization and future field test of coordinated control
  - Also evaluated impact of communications and communications delays
  - UNM working on electrical simulations
  - SAND2013-1603 report published in February

- Future steps
  - Sandia, PNM, UNM, NEDO, Tokyo Gas and Shimizu joint PVSC publication
  - Develop field demonstration plan