TECHNOLOGY PERFORMANCE REPORT

Smart Grid Demonstration Project

Public Service Company of New Mexico

PV Plus Battery for Simultaneous Voltage Smoothing and Peak Shifting

WORK PERFORMED UNDER AGREEMENT

DE-OE0000230

Project Type

Energy Storage

SUBMITTED BY

Public Service Co. of New Mexico

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Definitions

"AAC" refers to amperes AC.

"AC" refers to alternating current.

"ACE" refers to Area Control Error

"Advanced Carbon Battery" refers to the sealed lead acid battery technology with advanced carbon features being commercialized by EPM and Ecoult

"Applications Controller" refers to the separate controller integrated with BESS Controller which shall interact with PNM's system level algorithms.

"AUX" refers to auxiliary input

"BAT DPU" refers to the digital processing unit for a set of UltraBatteries (used for battery management).

"Battery Meter" refers to the metering point on the AC output of the associated BESS

"Battery System" refers to either the Smoothing Battery System or Shifting Battery System or both if used in the plural.

"BES" refers to battery energy storage.

"BESS" refers to battery energy storage system.

"BESS Controller" refers to the programmable controller supplied by Ecoult for control of the BES System

"BES System" refers to the entire BES system including the Smoothing Battery System, the Shifting Battery System, the PCS and any other components

"CAB" refers to a container of Advanced Carbon Battery cells mounted in racks complete with battery monitoring hardware, BAT DPUs and DC switchgear.

"CUB" refers to a container of Ultrabattery Battery cells mounted in racks complete with battery monitoring hardware, BAT DPUs and DC switchgear.

"DAQ" refers to Data Acquisition System

"DC" refers to direct current.

"Distributed Resource" a utility interactive (grid connected) inverter or converter and its interconnection system equipment connected in parallel to an electric power system to supply power to common loads, which includes electrical energy storage systems.

"DMS" refers to Distribution Management System

"DNP" refers to Distributed Network Protocol

"EPRI" refers to the Electric Power Research Institute

"f" refers to frequency

"G1 G2, G3, G4" refer to scaling and error correction gains

"GHG" refers to Greenhouse Gas

"GPS" refers to Global Positioning System

"HVAC" refers to Heating ventilating and Air Conditioning

"HE" refers to Hour Ending

"IEEE " refers to the Institute of Electrical and Electronics Engineers

"Inverter" refers to a bi-directional DC-to-AC and AC-to-DC inverter and its associated controls and power components to connect the PCS to the electrical grid as further described in Section 7.1.

"kV" refers to kiloVolts.

"kVAR" refers to kiloVolts Amperes Reactive.

"**kW**" refers to kiloWatts

"$\mathbf{kW_{base}}$ " refers to baseline kW measurement

"$\mathbf{kW_{shift}}$ " refers to shifted kW measurement

"$\mathbf{kW_{smooth}}$ " refers to smoothed kW measurement

"LCOE" refers to levelized cost of energy

"LPF" refers to low pass filter

"MPPT" -refers to Maximum Power Point Tracking

"NWS" refers to National Weather Service

"NOAA" refers to National Oceanic and Atmospheric Administration

"OSI ACE" refers to OSI Advanced Calculation Engine

"PI" refers to Process Information

"PNM" refers to Public Service New Mexico, the owner of the PNM Project.

"PNM's Distribution Operations" refers to PNM's operation center for power distribution that will control the BES System through a communication link with the BESS Controller.

"PNM Project" refers to the demonstration of BESS in conjunction with a 500kW solar photovoltaic power plant by PNM in the greater Albuquerque area of New Mexico.

"PNM RTU" refers to the PNM supplied RTU

"PNM WSM" refers to PNM Wholesale Marketing Department

"**Primary Meter"** refers to the metering point on the AC output of the high side of the 480/12470 transformer

"PCS" refers to the power conversion system, which is a subsystem of the BES System

"PV" refers to photovoltaic

"PV Meter" refers to the metering point on the AC output of the associated 500kW PV resource

"PCC" refers to the point of common coupling of the BES System with the electric grid, for this PNM Project, the 12.47 kV connection point.

"ROI" refers to Return on Investment

"RTU" refers to remote terminal unit.

"SCADA" refers to supervisory control and data acquisition.

"Shifting Battery System" refers to a single string of CABs, which is further defined in Section 3.1.

"Smoothing Battery System" refers to a single string of CUBs, which further defined in Section 3.1.

"SoC" refers to State of Charge

"SoCREF" refers to Reference State of Charge

"**UltraBattery"** (trademarked) refers to the sealed lead acid battery technology with ultra-capacitor features being commercialized by Ecoult (traded under the mark UltraBattery^{TM})

"T1" refers to PV Low Pass Filter Time Constant

"T2" refers to AUX1 (load) Low Pass Filter Time Constant

"T3" refers to AUX2 (ACE) Low Pass Filter Time Constant

" TW" refers to PV moving average Time Window

"UPS" refers to an uninterruptable power supply.

"VAC" refers to Volts alternating current**.**

"VDC" refers to Volts direct current**.**

"Whr" refers to Watt-hour

"WSM" refers to Wholesale Marketing

1: Overview of the Energy Storage Project

The Public Service Company of New Mexico (PNM) demonstration project installed an energy storage system composed of two elements: a 0.5MW Smoothing Battery utilizing Ultra Batteries and a 0.25MW/0.99MWhr Peak Shifting Battery utilizing Advanced Lead Acid Batteries, both manufactured by Ecoult/East Penn Manufacturing. These two systems combined with a single 0.75MW Power Conditioning System, are co-located with a separately installed 500kW solar PV plant, at a utility-owned site, to create a firm, dispatchable, renewable generation resource. [1]. This hybrid resource provides simultaneous voltage smoothing and peak shifting through advanced control algorithms, and is capable of easily switching between end-of-feeder and beginning-of-feeder configurations to demonstrate simultaneous smoothing and shifting encompassing a range of applications.

1.1 - List of Recipient, Sub-Recipients and Respective Roles:

Recipient	***Responsibilities/Role***
Public Service Co. of New Mexico	Project lead, algorithm development, source of signal to BESS
Ecoult/East Penn Manufacturing	Install and support battery system
University of New Mexico	Modeling, algorithm development
Northern New Mexico College	Package data- separated for the individual steps depicted in the methodology
Sandia National Laboratories	Consult on control algorithms

1.2 - Objectives:

- Demonstrate PV-plus-battery to mitigate voltage-level fluctuations and enable peak shifting
- Quantify and refine performance requirements operating practices, and cost and benefit levels associated with PV-plus-battery as a firm dispatchable resource
- Achieve 15 percent or greater peak-load reduction on distribution feeder using PV plus battery.
- Generate, collect, analyze and share data to advance grid efficiency, optimize supply and demand, and increase reliability

[1] PNM also installed an adjoining 500kW PV installation which was not funded through the DOE ARRA program

- Validate and support the nationwide effort to develop the next-generation utility system and further the integration technologies and standards for renewables and energy efficiency

- Enable distributed solutions that reduce GHG emissions through the expanded use of renewables.

1.3 - Description of Energy Storage Technologies and Systems

The project is a genesis of underlying efforts that began in 2008 under the EPRI Smart Grid Demonstration Program. In this EPRI collaboration extensive use case analyses were developed to describe broad and underlying communication/control architectures for a Smart Grid that incorporates high penetration solar PV. The Prosperity Energy Storage Project was then proposed under the ARRA DOE Smart Grid Storage Demonstration Solicitation in 2009 and is the first ARRA-funded storage demonstration to go online. Major contracts with the DOE, vendors and university partners were finalized in the fall of 2010 and construction began in May 2011, after site permitting was completed. The project was commissioned and operational on September 19, 2011. The system one Line diagram is presented in Figure 1 below.

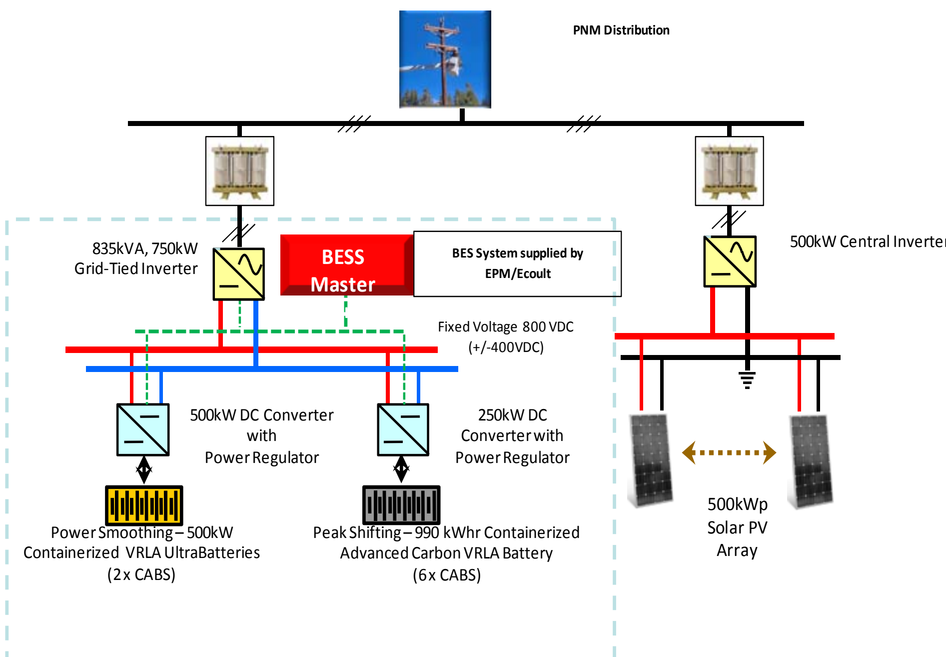

Figure 1 - System One Line Diagram

1.4 Key Project Milestones and Impact Metrics:

Phase	***Milestone***	***Target Completion Date***	***Actual Completion date***
I – Design & Engineer Solution	Negotiate and finalize SGDP Award Revise PMP	30-October-10 30-November-10	30-October-10 30-November-10
II - Establish & Develop Control Strategy	Battery Manufactured Models created, calibrated with algorithms prioritized	20-May-11	7/30/2011 2/1/2012
III – Construct & Commission Demonstration	System Installed and Commissioned	16-August-11	11/1/2011
IV - Demonstrate Evaluate and Report	Successful Completion	24-February 14	on track

Table 1 Project Milestones

1.5 - Applicable Energy Storage Applications and Smart Grid Functions

Electric Energy Time Shift -Enabled through peak shaving and firming utilizing different source signals into the shifting algorithm

Area Regulation - Enabled through application of Area Control Error signal into the battery smoothing algorithm

Voltage Support - Enabled through peaks shaving efforts where substation voltage signals are incorporated into the shifting algorithm

T&D Upgrade Deferral - Enabled through peak shaving and incorporation of a distributed resource to relieve substation service requirements

Renewable Energy Time Shift - Enabled through peak shaving and firming of the PV energy to align PV production to utility system peaks

Renewables Capacity Firming - Enabled through firming of the PV energy to align PV production to utility system peaks

1.6 - Grid or Non-Grid Connected Impacts and Benefits

The main benefits expected from the demonstration include deferred peaking generation capacity investments and deferred distribution capacity investments. Benefits will be derived through the avoided costs of peaking plant investment, substation or feeder expansion due to peak shaving and avoided cost of capacitor banks and voltage regulators by smoothing PV ramp rates and minimizing voltage fluctuations. Creation of a reliable, dispatchable renewable resource is also intended to reduce electricity line losses and account for pollutant emission and fuel avoidance from fossil based peak shaving resources.

Optimized Generator Operation

These benefits are enabled by the shifting function of the demonstration. Specifically, various algorithms have been designed, tested through computer modeling and implemented via the test plan to determine the best mode of creating a firm, peaking, renewable energy resource.

Deferred Generation Capacity Investments

These benefits are attributed to the ability of the system, as a firm peaking resource, to allow avoidance of fossil based peaking resource additions. By establishing a firm resource from PV a much higher capacity factor can be allowed these systems in resource planning.   Benefit will be measured by success of targeting an increase in allowable peak contribution of PV (from 55% current to 90% - typical of a gas peaking unit).

Deferred Distribution Capacity Investments

These benefits are enabled by the smoothing function of the demonstration.   The smoothing function alleviates voltage swings and avoids extra distribution system protection in the face of high penetration PV. The cost of avoided protection for an unsmoothed system will be stacked with other benefits.

Reduced Electricity Losses

The demonstration will contrast baseline and tested system losses. Losses will be calculated by determining where the losses are originated and then projecting upstream to derive the associated reduced generation kWh.

Reduced Carbon Dioxide Emissions

Reduced losses and substitution of fossil fuel based generation with PV will reduce carbon dioxide emissions. Establishing the amount of such reductions requires: 1) tracing the load profile of the load change attributed to the project back to ascertain how the generation dispatch was affected, 2) determining which generation units had their output reduced (and which had their output increased, if appropriate), and 3) associating with each affected generation unit a CO2/kWh emission rate.

Reduced SOX, NOX, and PM-2.5 Emissions

Establishing these emissions effects involves tracing the load profile to the generation origin method, as is required for CO_2 impact, but in this case the effected generation output is associated with an SOX, NOX, and PM-2.5 Emissions rate.

1. 7 - Synopsis of Steps Taken to Achieve Interoperability and Cyber Security

PNM has developed and successfully submitted a comprehensive Cyber-Security plan to DOE relating specifically to this project. The plan has identified and documented distinct steps to identify, isolate and mitigate all security risks associated with its Smart Grid program, both for the near-term energy storage applications for grid support deployment and for longer-term smart grid investment decisions. PNM's plan envelopes the 10 phases below, which consist of 183 controls from NIST SP 800-53. PNM has completed and documented results of the first eight phases. The results from these eight phases consist of 153 documented controls.

- Phase 1 - Initiation
- Phase 2 - Concept
- Phase 3 - Planning
- Phase 4 - Requirements Analysis
- Phase 5 - Design
- Phase 6 – Development
- Phase 7 – Security Test
- Phase 8 - Implementation
- Phase 9 - Operations And Maintenance
- Phase 10 - Disposition Phase

PNM also continues to be an active participant in the Smart Grid Interoperability Panel (SGIP) efforts, maintaining its voting privileges since the inception of the effort. Additionally, PNM has been participating on the new Domain Expert Working Group (DEWG) within the SGIP focusing on Distributed Renewables, Generators, and Storage. Participation on this DEWG will allow PNM to provide both outreach to the rest of the industry on experiences and lessons learned from the Prosperity Energy Storage Project as well as inform this project from other efforts and needs identified through the DEWG. This will further guide our research plan.

PNM has also been actively reviewing efforts from the Cyber Security Working Group of the SGIP. Another effort exists between NIST and the Renewable and Sustainable Energy Institute to identify the long term research requirements to overcome the major technological and measurement challenges associated with deployment of the smart grid. PNM is a member of Working Group 2 of that effort focused on integration of distributed generation (including renewables) and energy storage with the grid (including micro-grids and local energy control systems).

1.8 - Synopsis of Interactions with Project Stakeholders

The following table outlines outreach activities and project related publications that have been externally disseminated.

Title	Description	Expected (or Actual) Completion Date	Intended Audience	Benefit to Audience
TPR	Technical Progress Report	07/12	DOE	Update on project results, issue and resolution ID, lessons learned and next steps
Smart Grid Update	Update to NM Public Regulation Commission	4/16/2012	NMPRC	Update on PNM SSG activities with focus on DOE Storage Project
PNM PV + Storage Update	Update with project results to EPRI PDU (storage and renewable integration advisory councils)	2/13/2012	EPRI staff and members	Present key findings, issue and lessons learned on project
Maximizing the Benefits of Energy Storage Combined with Utility Scale PV	Update with project results to ESA – to be published in proceedings	5/2/2012	ESA	Present key findings, issue and lessons learned on project
Applying UltraBattery® Technology to Deliver MW Scale Energy Storage Solutions for Smoothing and Shifting of Solar Power	Description of Battery Technology and with project results to Intersolar Europe Conference – abstract available	6/13/2012	InterSolar Europe	Display abilities of battery technology deployed against PV
Mitigating Renewable Energy Intermittency with Energy Storage	Highlight drivers for storage in the face of renewable energy growth	3/27/2012	NM Tech	Educate on utility system operations and how storage can allow increased renewables, describe DOE project and present results
Renewable Energy and the Need for Energy Storage	Highlight drivers for storage in the face of renewable energy growth - describe DOE project i	12/20/2011	NM Assoc. of Energy Engineers	Educate on utility system operations and how storage can allow increased renewables, describe DOE project and present results
Renewable Energy and the Need for Energy	Highlight drivers for storage in the face of renewable energy growth - describe DOE project i	2/24/2012	NM Society of Prof. Engineers	Educate on utility system operations and how storage

Storage				can allow increased renewables, describe DOE project and present results
Public Service Co. of New Mexico (PNM) - PV Plus Storage for Simultaneous Voltage Smoothing and Peak Shifting	Update with project status to DOE	10/20/2012	EESAT – DOE Peer Review	Peer Review on project status
Modeling of PV plus storage for peak shifting and simultaneous smoothing at Mesa del Sol	Description of modeled system, modeling techniques and results to date	10/18/2012	EESAT	Expose how storage can be modeled on a utility system, describe approach used and present results
Integrating Utility Based PV and Storage on a Smart Grid Foundation	Describe foundational/architecture based on EPRI Inteliigrid™ used to platform the data acquisition and control system in a Smart Grid Environment	4/17/2012	SEPA Utility Only Conference	Expose the level of sophistication needed to properly site and run a distributed asset in a cyber secure utility environment
PV Smoothing and Shifting Utilizing Storage Batteries	Update with project status to EPRI SG Demo	04/02/2012	EPRI Smart Grid Demonstration Advisor Mtg	Share lessons learned and align to overall SG efforts with EPRI
Maximizing the Benefits of PV with Energy Storage	Update with project status to Storage Week Conference	Upcoming 06/25/2012	Storage Week	Expose how storage can be modeled on a utility system, describe approach used and present results
Integrating Renewable Energy with Battery Storage	Demonstrate how PNM is facing challenge of intermittency associated with increased renewables	03/22/2012 02/23/2012	IEE Power the People Conf NM Green Grid Initiative	Explain how storage can help mitigate effects of renewable intermittency
PNM smart grid demonstration project from modeling to demonstration;	Description of modeled system, modeling techniques and results to date - abstract at Link below table	2012	Innovative Smart Grid Technologies (ISGT), 2012 IEEE PES;[2]	Expose how storage can be modeled on a utility system, describe approach used and present results
Analysis of battery storage utilization	Analyzing modeling techniques and algorithm	2012	Innovative Smart	Expose how control

[2] IEE Papers Link: http://ieeexplore.ieee.org/search/searchresult.jsp?searchWithin=p_Authors:.QT.Abdollahy,%20S..QT.&newsearch=partialPref

for load shifting and peak smoothing on a distribution feeder in New Mexico;	development for battery control abstract at Link below table		Grid Technologies (ISGT), 2012 IEEE PES;	algorithm can be developed and tested in a modeling environment
Smoothing and Shifting PV – Applying Energy Storage to Enhance the Benefits of Renewable Energy	Highlight drivers for storage in the face of renewable energy growth - describe DOE project	05/16/2012	World Renewable Energy Forum	Educate on utility system operations and how storage can allow increased renewables, describe DOE project and present results
PV Output Smoothing with Energy Storage	Specific description of smoothing algorithm	Submitted for publication	IEEE PES	Describe benefits of using different input signals to control smoothing
A Comprehensive Approach Toward Distribution System Forecasting	Description on how modeling can be used to forecast high levels of PV and other loads and how storage can mitigate	Submitted for publication	IEE Journal publication	Describe modeling efforts of high pen PV EV and lessons learned on how to accommodate into utility system

Table 2 - PNM Prosperity Energy Storage Project DOE-OE-0000230 Outreach Activity Summary - up to July 2012

Additionally PNM has developed a public web portal that provides live data from the demonstration, project background materials and educational resources relating to renewable energy and energy storage. PNM will use this outreach tool to enhance high school and college curriculum relating to renewable energy. The public website can be reached through http://www.PNM.com/solarstorage. The site requires Adobe SVG Viewer and the website is compatible with Internet Explorer (IE) only.

2 Description of Energy Storage Technologies and Systems

2.1 Location of the Storage System and Demonstration Activities

The project is located south of Albuquerque New Mexico in PNM's service territory on PNM owned land. It is adjacent to Mesa del Sol, Albuquerque International Airport and Sandia National Labs.

Figure 2 - PNM Project Site Map

2.2 System Description

The key components of the project feature

- 500kW PV installation with 2,158 Schott 230 solar panels (not funded by DOE)
- SMA 500kW PV Inverter (not funded by DOE)
- Ecoult/ East Penn Manufacturing Energy Storage Solution:
    - 6 Battery Containers each containing 160 Advanced Lead Acid batteries – with an energy shifting functionality Energy rating is 1 MWh.
        - Each container weighing approx. 49,700 lbs.
        - Stored energy is being dispatched as “firm” energy when energy demand increases, offsetting the peaking requirements of a natural gas during times of customer peak usage. This allows PNM to use renewable energy when it’s most needed.
    - 2 Battery Containers each containing 160 UltraBatteries– with an power smoothing functionality -
        - Each container weighing approx. 49,700 lbs.
        - Power Rating is 500kW
        - The UltraBattery Storage provides the ability to “smooth” the output of the solar facility. For example, when a cloud casts a shadow on the solar panels, the advanced battery system and smart grid technology immediately dispatches energy to fill the gap created by the cloud
- The PCS is be composed of:
    - 1 x 0.75 MW bi-directional Grid-Tied Inverter (designed for a 1MW rating);
    - 1 x 0.5MW bi-directional DC Converter for the Smoothing Battery System;
    - 1 x 0.25MW bi-directional DC Converter for the Shifting Battery System;
    - A main AC breaker for protection and provision of DC contactor functionality;
    - A DC capacitor pre-charge circuit;
    - An AC filter for the inverter output and DC filters per battery input with an option for AC EMI filters;
    - Inverter controls and protection by a digital processing unit (INV DPU) for the Inverter and each controllable set of DC Converters, and
    - 480 VAC power circuit.
- Ecoult Battery Management and Monitoring System
- Battery Power Conditioning System
- Data Acquisition and Control System collecting 220 points at minimum every second including
    - Solar field metrology
    - Solar field string monitoring
    - Battery system monitoring and control
    - PCS system monitoring and control

  - PMUs for both the site feeder and battery system with data capture ability at 30 samples per second
  - Separate, 1 second interval utility grade metering on the PV, Battery and overall site
  - Secure gateway managing point collection and protocol translation (MODBUS – DNP3)
  - Secure 2 way communication to PNM's Distribution Operations
  - Secure fiber connection to PNM's Data Center
  - Secure partner access to fielded equipment
  - Back Office OSIsoft® PI database with real time access through a Sharepoint portal
  - PI to PI functionality to share data with Project Partners
- Automated distribution system switching allowing the site to change configuration from "end of feeder" to "beginning of feeder" in terms of location of the distributed resource to allow evaluation of impact of energy storage at different locations on a grid

The system is laid out in a grid/isle fashion to minimize overall footprint and allow for efficient and safe access for maintenance and operation activities. Figure 2 details the overall plot plan including a 500kW Solar PV Plant (Not funded by DOE) installed concurrently with the DOE project. Figure 3 details the layout and dimensions of the battery system

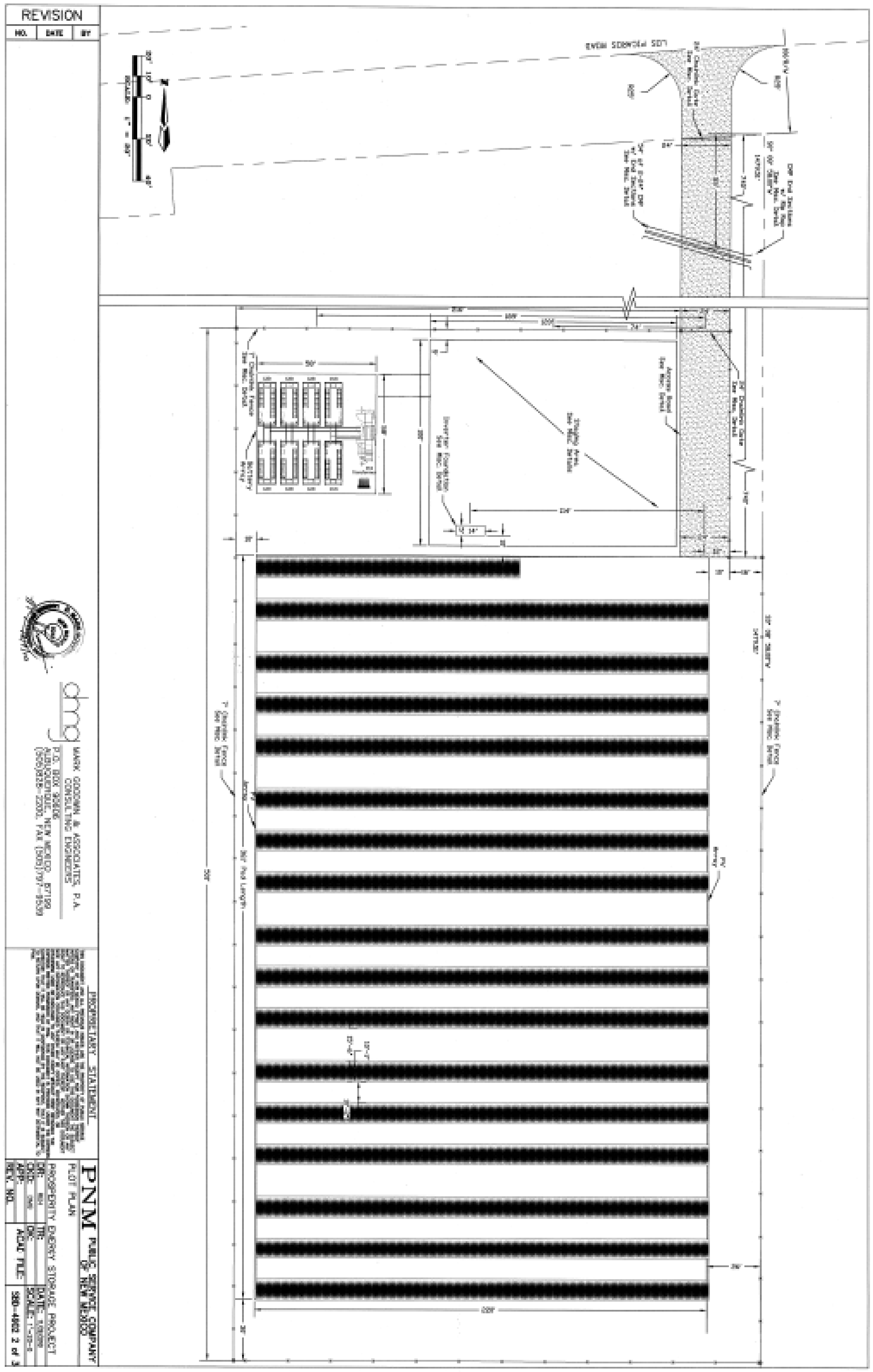

Figure 3 - PNM Prosperity Energy Storage Project Plot Plan

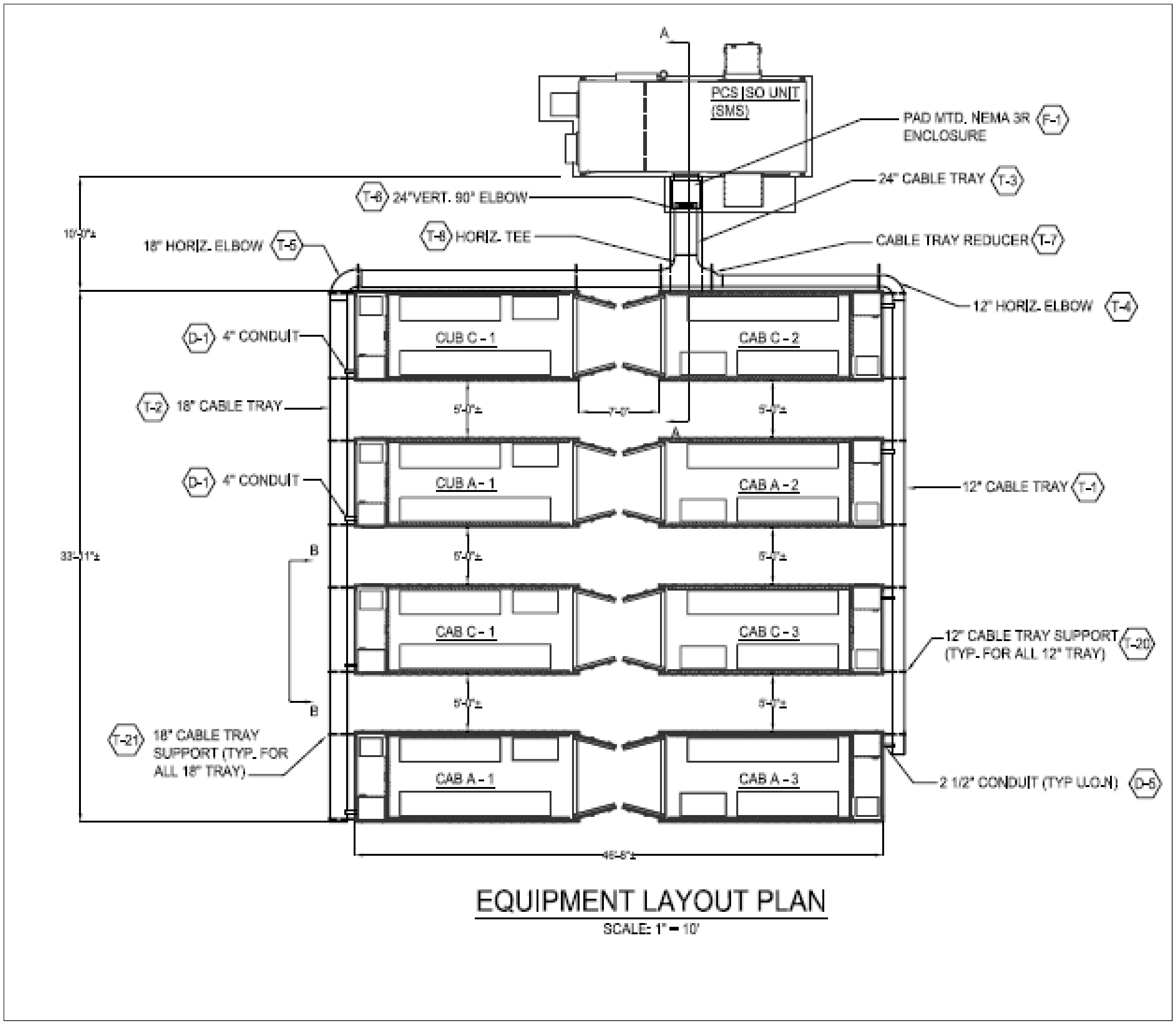

Figure 4 - Battery Layout Plan

The system one line diagram is provided in Figure 4 below. The electrical configuration of the system includes two inverters with two inverters, one serving the PV system and the other engrained in the battery PCS, see Figure 5. Both inverters feed the secondary side of a single dual core 12.47kV/480V transformer. Preference would be for one inverter with a common DC bus serving the PV and Battery system but grounding issues precluded this feature. The Battery System One Line Diagram is shown in Figure 6, below, which details the mater/slave relationship between the PCS and the BESS, which shows the master/slave relationship to the BESS.

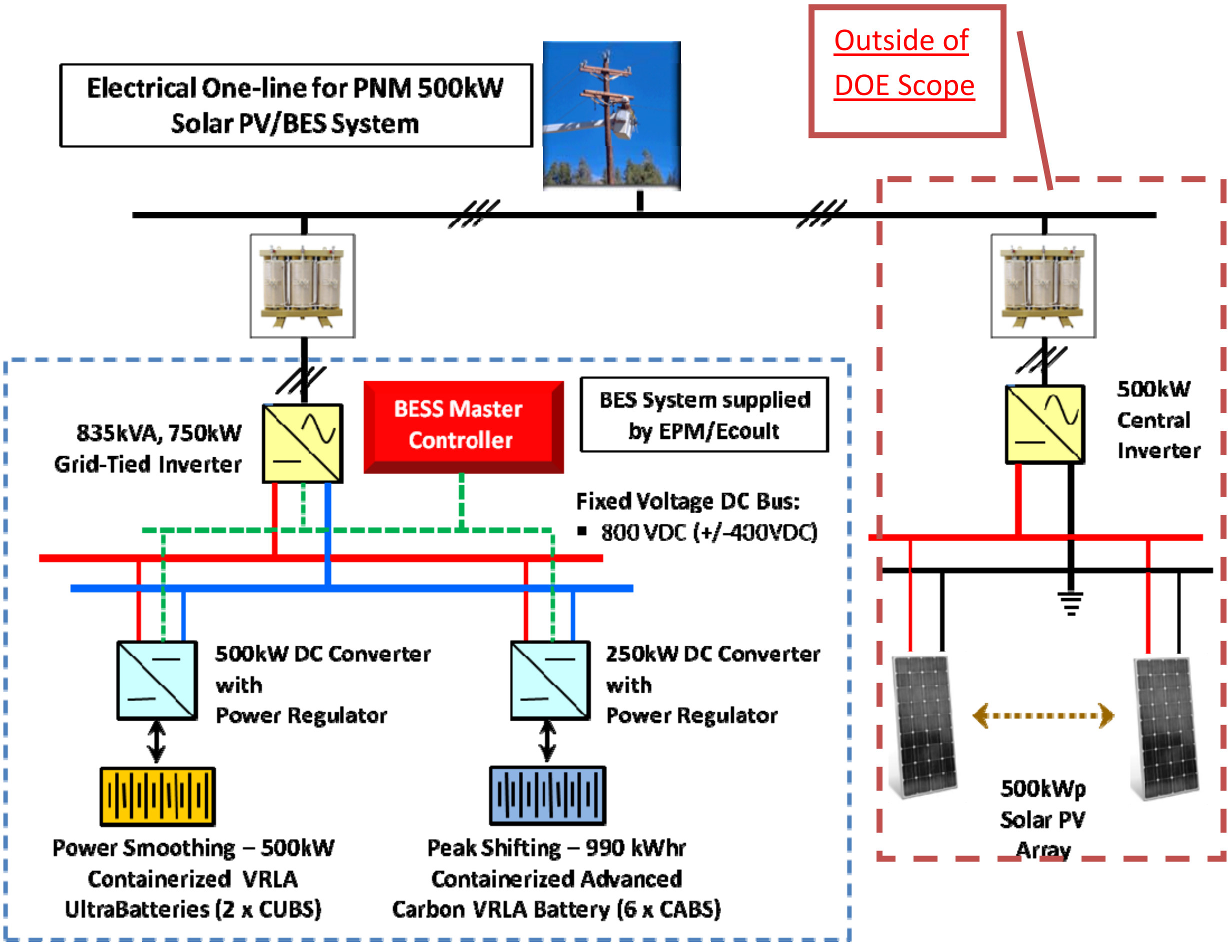

Figure 5 - System One Line Diagram

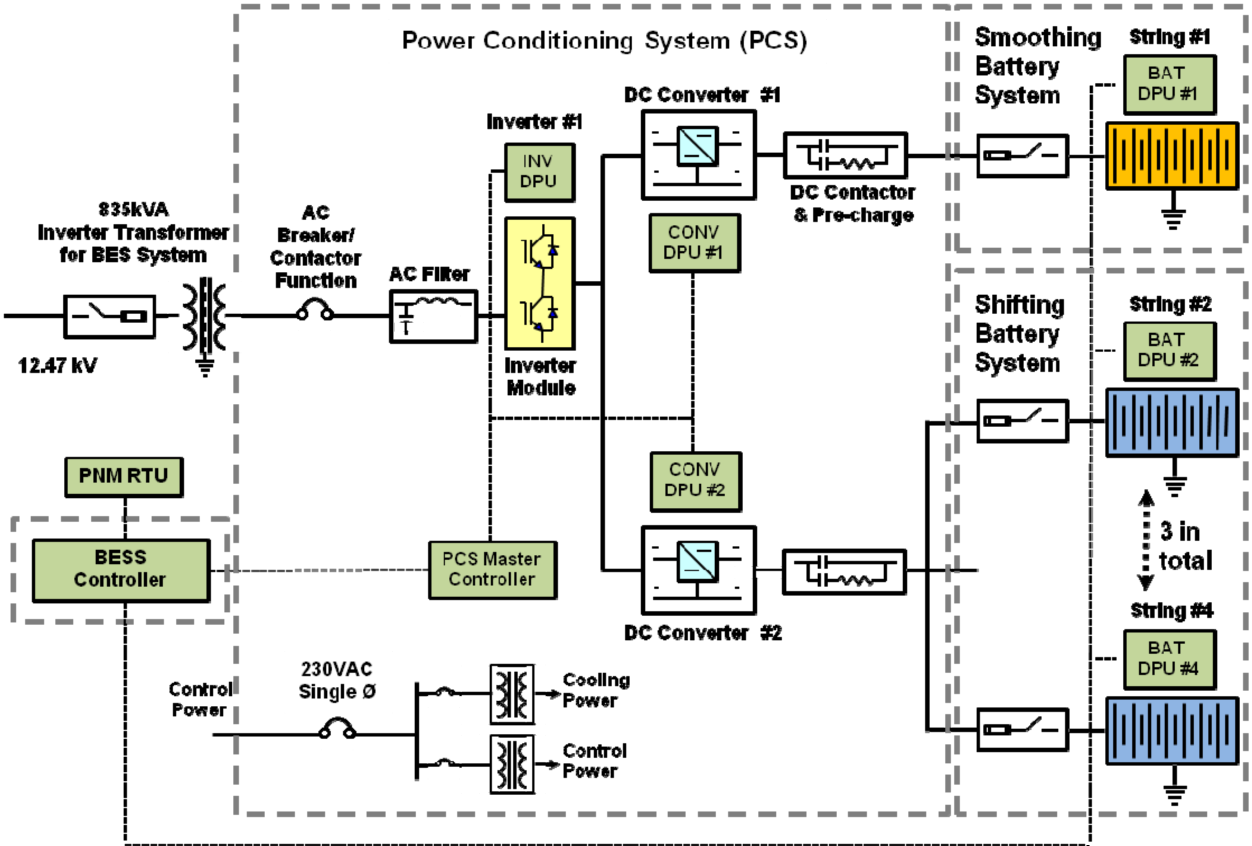

Figure 6 - Battery System One Line Diagram

Figure 7 below shows an aerial view of the plant (looking south) with the battery placed adjacent to the PV system. Note the large parking/staging site. This was required to accommodate the unloading of the battery containers, containers. For details, refer to the Transportation Considerations section below.

Figure 7 - PNM Prosperity Energy Storage Project - Aerial View

2.3 Data Acquisition System

The Data Acquisition system diagram, see

Figure 8, shows the system architecture and devices. The gateway is made up of a Cooper SMP with two Network Interface Cards (NICS). One takes 220 points from each device and sends to the back office for analysis every second with a time stamp from the GPS. The other NIC takes all points available from each device and reads into the gateway at sub-second intervals or when there is a change in value of the signal of each device. The gateway takes the protocol of each device and translates it into DNP3 protocol for back office analysis. The Gateway has the ability to process other protocols such as IEC61850. There are 12 devices on the master side behind the gateway's firewall. Each is described below along with its corresponding sub system.

2.3.1 Master Devices:

1. Intelliruptor (S&C Pulsecloser). Function: 3 Phase protective Device for utility Distribution Operations control for system protection. Media is over fiber to a Dymac converter to RS-232. Data is sent to Gateway over a DNP3 protocol
2. Single Phase Meter (Veris Industries E50C03)Function: To monitor voltage, power, amps, etc. from the Auxiliary load of the energy storage facility. Media is over an RS 485 and data is sent to the gateway over a MODBUS protocol
3. Carlo Gavazzi String Monitors – Function: 6 monitors for 166 string voltage and currents from solar panels. Media is a RS-485 and data is being sent to the gateway over a MODBUS protocol
4. PMU (SEL 451) – Function: Phasor Measurement unit for secondary metering of the sytem (PV & Battery functions). Media is over Ethernet and data is sent to the gateway 30 samples per second to the gateway over a IEEE C37.118 protocol
5. PMU (SEL 351) – Function: Phasor Measurement unit for the Primary Meter data or total system output. Media is over Ethernet and data is sent to the gateway 30 samples per second to the gateway over a IEEE C37.118 protocol
6. ION Meter 8600 meter (PV Meter) – Function: Recording voltage, Amps, KW, Kwh, etc for the PV system output from the inverter (AC). Media is over Ethernet and data is sent to the gateway in DNP3 protocol.
7. ION Meter 8600 meter (Battery Meter) – Function: Recording voltage, Amps, KW, Kwh, etc for the Battery system output from the PCS inverter (AC). Media is over Ethernet and data is sent to the gateway in DNP3 protocol.
8. ION Meter 8600 meter (PM Meter) – Function: Recording voltage, Amps, KW, Kwh, etc for the total system output from 12.47kv side of transformer. Media is over Ethernet and data is sent to the gateway in DNP3 protocol.
9. Advantech. BESS (Advantech UNO-3082) – Function: Battery controller, where the algorithm and control signals (analog) are sent for system functionality. Media is over Ethernet and data is sent and received to the gateway in DNP3 protocol.
10. Subsystem of the BESS: S&C HMI (Matrix MXE-1010). Function: Designed to receive the commands and communicate status to the BESS. Media is over Ethernet between the BESS and HMI in MODBUS protocol.
11. S&C HMI (Matrix MXE-1010). Function: virtual connection for S&C & PNM for system monitoring and remote Diagnostics. Two token authentication and 3 firewall passwords for virtual connection into HMI device. Media is Ethernet and no protocol for data transmission to the gateway.
12. Sunny Webbox (SMA TUS102431): Function: A central communication interface that connects the PV Plant and the operator through a virtual connection for system monitoring. Two token authentication and 3 firewall passwords for virtual connection

into Sunny Webbox.   Media is over Ethernet and data is sent and received to the gateway in MODBUS protocol.

a. Micrologger (CR3000 Campbell Scientific. Inc.): Function: take all inputs from Met Station, Pyranometer, and Temperature sensors. (Wind speed, irradiance, temp, etc). Media is over Ethernet and data is sent to the gateway in MODBUS protocol.
b. Subsystems of Micrologger:
c. Met Station (RH, Temp, Wind Speed, Irradiance)
d. 5x LI-COR Pyranometer
e. 5xTemperatore Sensors

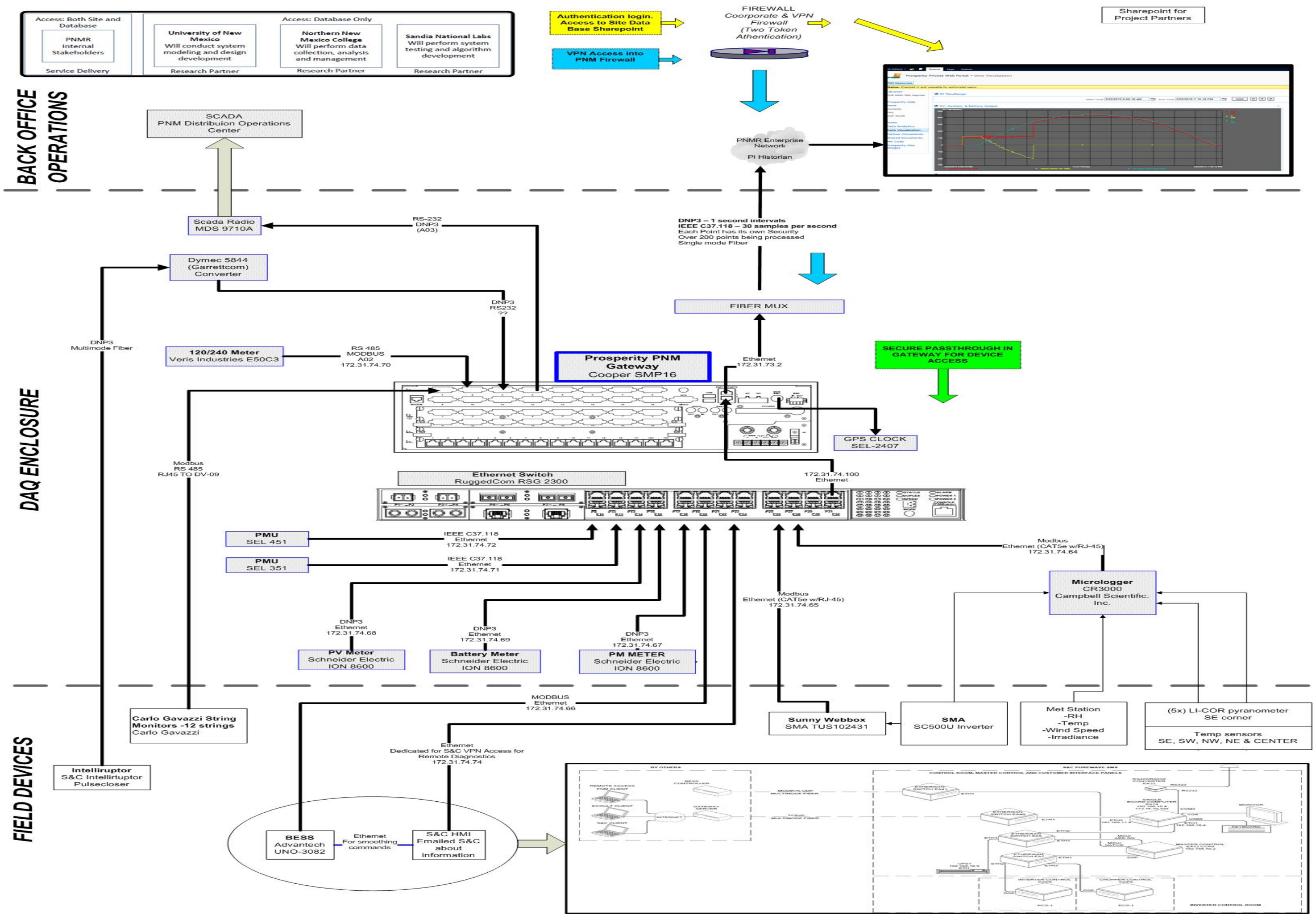

Figure 8 -Data Acquisition system architecture

2.4 Human Machine Interface Systems

2.4.1 PI Data Base

PNM's PI system is a suite of OSI Soft software solutions that support real time information gathering for subsequent analysis. The system can gather information from multiple external data sources, and stores the raw information in the data historian. t PNM's project gathers information from the DNP3 interface that collects all site information using the DNP3 protocol, the IEEE C37.118 interface that collects all site data using the IEEE C37.118 protocol. The system is capable of expanding to collect other data from sources such as internet weather data and system data from PNM operational systems. The PI Interfaces provide high-speed, fault tolerant data links from the field systems to the PI system.

PI data is being shared with project partners using PI to PI interfaces, currently populating OSI Soft PI servers at partner sites in real time. Current interfaces are operational between PNM and Sandia National Labs, PNM and Northern New Mexico College and PNM and the University of New Mexico.

The raw data is being transformed into operational intelligence through other applications in the PI software suite through applications such as PI Process Book, PI DataLink, and PI Webparts. PI Process Book provides a graphical environment in which to display data in real time. PI DataLink automates the retrieval of PI data into Microsoft Excel to use in calculations, analysis, and graphs. PI Webparts provide a tool for visualization in a web environment.

The integration into Microsoft Sharepoint, allows users to view real time data and calculations of multiple applications and data sources into one web environment. Lastly, PI Advanced Computing Engine provides an environment to create complex calculations and schedules with data stored in the PI Server. This allows users to write modules using Visual Basic to provide more capability than is available directly within the core OSI Soft programs, making for a much more powerful and flexible system. The PI suite of software addresses data security as well across the enterprise by allowing specific, administrator-designed permission levels down to the point, asset, or event frame allowing only authorized users access to data that they are authorized to view.

2.4.2 Information Portal

PNM's information portal supports information anywhere, anytime by anybody and enables transition from a data constrained organization to one that is information rich and robust. The portal is the front end of the Project's PI data base.

The Prosperity information portal and operational intelligence platform has been developed in three stages, as outlined below. Proprietary information functionality of the Portal is secure and permissions to project partners are granted and non Proprietary to the Public.

Stage I – Public Outreach

Stage II - Event Processing

Stage III - Situational Awareness

Stage I – Public Outreach

The information portal offers public outreach and educational materials. The portal is used to raise awareness of smart grid opportunities in the region and also informs interested stakeholders about the demonstration project and future deployment efforts applicable to the region. The portal supports static content such as, but not limited to, educational, videos, links, photos, white papers and web publications. Furthermore, the portal supports dynamic information presented as operational intelligence. Operational intelligence is a form of real-time dynamic, operational analytics which delivers visibility and insight into smart grid operations. Operational intelligence translates live information feeds and event data into real-time visualizations and actionable information. This real-time information can be acted upon in a variety of ways – such as executive decisions which can be made using real-time dashboards.

Stage II - Event Processing

Event processing is a method of tracking and analyzing (processing) streams of information (data) about things that happen (events), and deriving a conclusion from them. Complex event processing, or CEP, is event processing that combines data from multiple sources to infer events or patterns that suggest more complicated circumstances. The goal of CEP is to identify meaningful events and respond to them as quickly as possible.

These events may be happening across various layers of operations or they may be news items, text messages, social media posts, economic triggers, weather reports, or other kinds of data. An event may also be defined as a "change of state," when a measurement exceeds a predefined threshold of time, temperature, or other value. CEP will give PNM a new way to analyze patterns in real-time, and help the Distribution Operations Department communicate better with IT and other shared service departments.

Stage III - Situational Awareness

Situational awareness is the perception of environmental elements with respect to time and/or space, the comprehension of their meaning, and the projection of their status after some variable has changed, such as time. It is also a field of study concerned with perception of the environment critical to decision-makers in complex, dynamic areas from power plant operations to command and control, and as well distribution services such as outage management, fault identification, system restoration, field operation and substation operation.

Situational awareness involves being aware of what is happening in the system to understand how information, events, and one's own actions will impact goals and objectives, both immediately and in the near future. Lacking or inadequate situational awareness has been identified as one of the primary factors in accidents attributed to human error. Thus, situational awareness is especially important in work domains where the information flow can be quite high, and poor decisions may lead to serious consequences.

Having complete, accurate and up-to-the-minute situational awareness is essential where technological and situational complexity on the human decision-maker is a concern. Situational awareness has been recognized as a critical, yet often elusive, foundation for successful decision-making across a broad range of complex and dynamic systems.

Features of the portal include

- Visualization of any of the PI Tags, see Figure 9, currently selected variables include,
    - Primary, PV and Battery Meters
    - Irradiance (center of array)
    - Smoothing and Shifting Batteries SoC
    - Battery and Primary meter KVAR
- Data can be visualized and extracted from a wide range of time series, from days to minutes.
- Data can also be exported to Excel from the presented graphs.

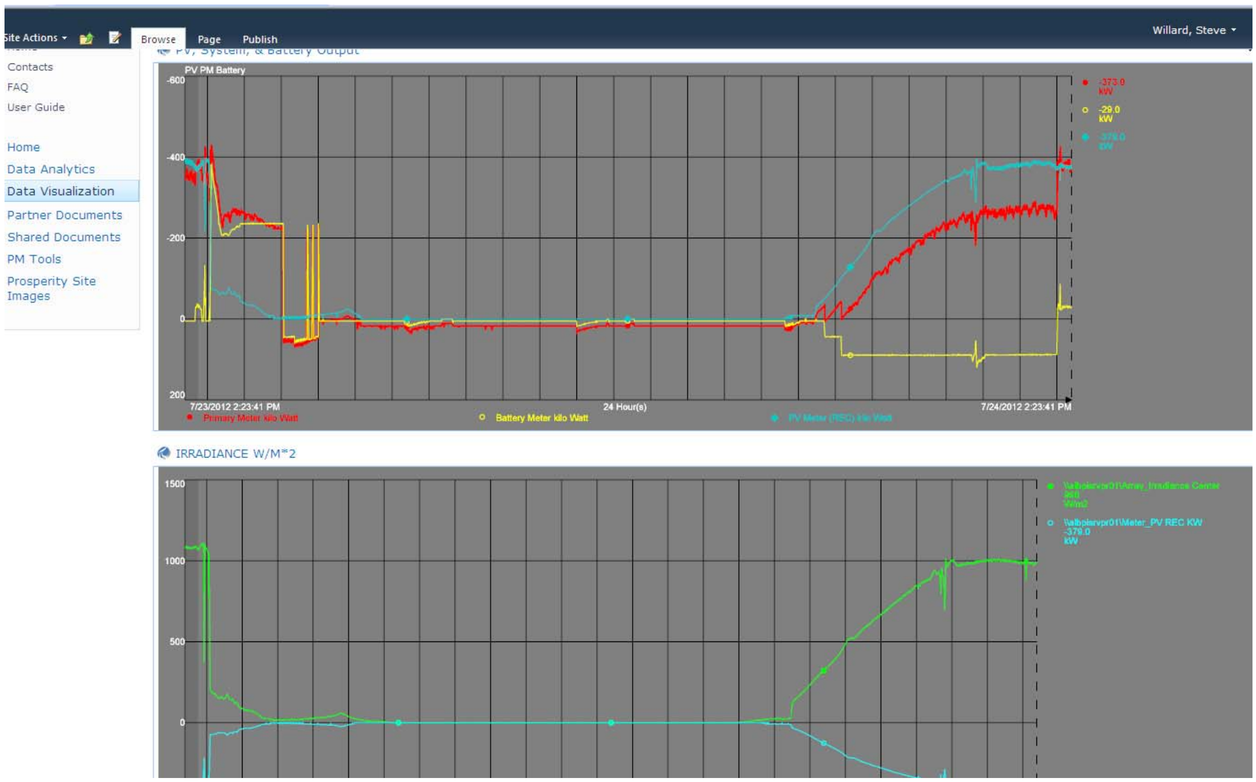

Figure 9 -PNM Sharepoint Data Visualization Screen Shot

2.5 Environmental, Health, and Safety Considerations

2.5.1 Environmental

DOE completed an Environmental Assessment (EA) for the project in August 2010 and DOE issued a Finding of No Significant Impact (FONSI) on Sept 17, 2010. The EA concluded:

“PNM's proposed project could provide a minor reduction of greenhouse gas emissions and have a net beneficial impact on air quality in the region. In addition, there would be a positive socioeconomic benefit resulting from the infusion of $5.8 million into the regional economy.”

2.5.2 Health and Safety

The BESS was designed, manufactured and tested in conformance with the applicable requirements of the latest editions, revisions and addenda of the codes and standards published by the following authorities:

- ANSI American National Standards Institute
- IEEE Institute of Electrical and Electronics Engineers
- NEC National Electrical Code
- NEMA National Electrical Manufacturers Association

- NESC® National Electrical Safety Code®
- NFPA National Fire Protection Association
- OSHA Occupational Safety and Health Administration
- UL Underwriters Laboratories

Door and Panel Safety Features

All electrical power sections/compartments within a battery container that have hinged doors, including the safety barrier described below, are equipped with lockable handles compliant with the National Electrical Code and National Electrical Safety Code®. All sections/compartments that have removable panels fastened with bolts are compliant with the National Electrical Code and National Electrical Safety Code®.

All applicable safety interlocks are in compliance with the National Electrical Code and National Electrical Safety Code®.

Safety Barriers

All live power is behind a safety barrier or within compartments such that the operator may enter the control section within the PCS without having access to live power, excluding control power.

The safety barriers are in compliance with the National Electrical Code and National Electrical Safety Code®.

Safety Features for CUBs and CABs

All CUBs and CABs have VRLA battery safety features specified by National Electrical Code, National Electrical Safety Code®, and IEEE1187. Hydrogen detectors are mounted on the ceiling of the containers, which shall energize explosion proof ventilation fans if hydrogen gas is detected. The detectors are interlocked with the BESS Controller for indication

The following meters, indicating lights, control switches and pushbuttons are mounted within the control section of a container or external to the containers for easy access from the entry door behind a safety barrier that protects the operator from any live power:

- Human machine interface (HMI) terminal to display, as a minimum, the following:
- DC power, voltage and current per DC Converter
- AC voltage, real power and reactive power of the Inverter
- PCS status
- PCS and Battery System fault messages
- Ready light

- AC power on/off status lights
- Cooling System on/off status lights
- UPS healthy light (alarm)
- Remote/Local Selector Switch with indicating lights
- Local on/off pushbuttons for each DC Converter
- Battery Power increase/decrease pushbuttons for each DC Converter
- Two Energized indication lights, one lit when energized, and one lit when de-energized (powered from UPS)
- E-Stop pushbutton

2.6 Transportability considerations

The containers were transported from the factory assembly site across the U.S. in approximately 5 days. Special consideration was given to the following:

- The gross weight requirements dictated special permitting and adherence to Department of Homeland Security rules preventing overweight transportation at night in certain states.
- The site design accommodated the required crane pick, lift and drop clearances, allowing for efficient unloading and placement
- A detailed staging plan was put into place to ensure the furthest units from the crane were placed first. The plan allowed for a total of 2.5 hour unload sequence.

The photos below show the convoy and the craning activities.

Figure 10 - Battery Convoy Arriving at Site

Figure 11 - Battery Installation

Figure 12 - Battery Installation

3 Analysis Methodologies

3.1 Goals & Objectives

3.1.2 Project Goals

- Quantify and refine performance requirements, operating practices, and cost versus benefit associated with PV-plus-battery as a firm dispatchable resource
- Achieve 15 percent or greater reduction on distribution feeder peak-load using PV plus battery. Section 3.1 describes current baseline data and detail relating to the 15% target.
- Generate, collect, analyze and share data to quantify the benefit of PV plus battery with respect to grid efficiency, optimization of supply and demand, and increase in reliability
- Validate and support the nationwide effort to develop the next-generation utility systems and Smart Grid technologies and standards that support the full integration renewable, distributed resources and energy efficiency
- Enable distributed solutions that reduce GHG emissions through the expanded use of renewables.

3.1.3 Project and Analysis Objectives

The project objectives are to identify, evaluate and compare various load shifting and peak shaving methods which can be made possible by utilization of a utility-scale battery.

The two main objectives of this demonstration project are:

1. Demonstration of energy shifting to the typical system peak (firming) by planned (“slow”) action from the battery, and demonstration of shifting to the typical substation/feeder peak (peak shaving) by planned (“slow”) action from the battery, and
2. Simultaneous smoothing of the Photovoltaic plant output by fast-response counter-action from the battery.

Secondary analysis objectives are:

3. Optimization of battery operation for arbitrage purposes, while meeting objectives 1 and 2
4. Optimization of battery operation for longer battery lifetime, while meeting objectives 1 and 2
5. Potential for real-time decision making regarding based on solar and load forecast and utilization of optimization algorithms for objectives 1-4

6. Assess additional system benefits through modeling where physical measurement or demonstration isn't practical. For example, demonstrate PV-plus-battery to mitigate voltage-level fluctuations

Detailed description of objectives:

(1) Shifting demonstration of power peak shifting from the typical system peak by planned ("slow") action from the battery (both firming and peak shaving).

This objective will be evaluated based on the following experimental design:

1. Baseline testing. Record observed AAC, VAC, kW, kVAR, f, as a function of time. Time step is 1 second intervals.
2. Load shifting testing. Controllably, discharge energy (shifting) battery based on a given algorithm and/or schedule. Record observed AAC, V,AC kW, kVAR, f, and SoC of the battery as a function of time. Time step is to be the same as used for baseline testing.
3. Compare the following inputs and outputs: kW, kWh, f, and SoC of the battery. Calculate the following parameters:
    a. Instantaneous peak load reduction: kW_{base} - kW_{shift}
    b. Percentage of instantaneous peak load reduction: (kW_{base} - kW_{shift})/ kW_{base}
    c. Total load reduction: kWh_{base} - kWh_{shift}
    d. Percentage of total peak load reduction: (kWh_{base} - kWh_{shift})/ kW_{base}
4. Repeat #2 and #3 for pre-determined shifting schedules and algorithms
5. Compare with modeling and simulation results

(2) Smoothing of the Photovoltaic plant output by fast-response counter-action from the battery.

This objective will be evaluated based on the following experimental design:

1. Baseline testing. Record observed AAC, V,AC, kW, kVAR, f, as a function of time. Time step is to be as small as possible, preferably 1 second, but may be limited by the hardware.
2. Smoothing performance testing. Discharge and charge the power (smoothing) battery based on a local control algorithm and/or remotely provided schedule. Record observed AAC, V,AC kW, kVAR, f, and SoC of the battery as a function of time. Data sampling and control time step is to be the same as used for baseline

testing. In preparation for this step, it is necessary to develop and implement a control algorithm for PV output smoothing.

3. Compare the following inputs and outputs: kW, kWh, f, and SoC and number of charge/discharge cycles of the battery. Calculate the following parameters:
    a. Instantaneous peak load reduction: kW_{base} - kW_{smooth}
    b. Percentage of instantaneous peak load reduction: (kW_{base} - kW_{smooth})/ kW_{base}
    c. Total load reduction: kWh_{base} - kWh_{smooth}
    d. Percentage of total peak load reduction: (kWh_{base} - kWh_{smooth})/ kW_{base}
4. Repeat #2 and #3 for pre-determined smoothing algorithms
5. Compare with modeling and simulation results

(3) Estimate the energy arbitrage value of the battery, while meeting objectives (1) and (2)

This objective will be evaluated based on the following calculations:

1. Obtain LCOE for PNM on a daily and hourly basis for a period of a year
2. Calculate total avoided cost (savings) for PNM for each of the load shaving scenarios

(4) Estimate the impact of battery operation on battery lifetime, while meeting objectives (1), and (2)

This objective will be evaluated based on the following calculations:

1. For each of the load shaving scenarios described, calculate following
    a. total amount of kWh charged and discharged
    b. total number of cycles
    c. percent of charge and discharge for each cycle
2. Compare calculated cycles and kWh to the manufacturer's recommended values

3.1.4 Test Plans and Associated Analysis Questions and Research Hypothesis

The following list summarizes planned tests and control strategies identified for PNM's Smart Grid Demonstration project. The smoothing experiments set will have the goal of maximizing avoided costs benefits associated with reducing PV intermittency impacts on the utility system while maximizing lifetime of the battery. Peak-shifting experiments will have the same goal of maximizing avoided costs benefits and maximizing lifetime of the battery, while at the same time will be responsive to different economic and or/priority signals from utility.

The Test Plans are briefly described below. A complete explanation of the Test Plans appear in the Section 3 Appendix B

- Baseline Test - establish baseline performance of the PV system output by gathering data over long periods covering various weather conditions and seasons.
- Control strategy and Test Plan 1 - Smoothing PV - Demonstrate the effectiveness of battery-based smoothing for various feeder configurations and weather conditions. The goals are to determine the optimal amount of smoothing needed for voltage swing mitigation and the best input signal and control parameters.
- Control strategy and Test Plan 2 - Shifting PV for Firming Purposes - (day ahead) Demonstrate ability to shape PV-battery system output to optimize the value of the PV energy delivered. Determine the value of a more accurate day ahead PV forecast to increase the dependability of PV energy firming.
- Control strategy and test Plan 3 - peak shifting PV– demonstrate a 15% reduction in the feeder peak load through peak shaving
- Control strategy and Test Plan 4 - optimized peak shifting – add energy arbitrage capabilities to Test Plan 2
- Control strategy and Test Plan 5 - optimized peak shifting and smoothing – combining and optimizing all functionality.

3.2 Methodologies For Determining Technical Performance

3.2.1 Smoothing Algorithm Modeling

3.2.1.1 Smoothing Modeling – Moving Average and Moving Median Algorithms

The PV output ramp rate depends greatly on cloud cover and cloud type conditions. For a partly cloudy day, the PV system output could fluctuate significantly and rapidly. An important concern with the control of BESS is the charge/discharge rates (or `ramping' rates) capability that the battery needs to have to effectively smooth out the ramp of PV output.

The purpose of smoothing algorithm is to mitigate abrupt changes in PV power output due to clouds moving over the footprint of the PV array. Figure 13 below shows an example of such smoothing.

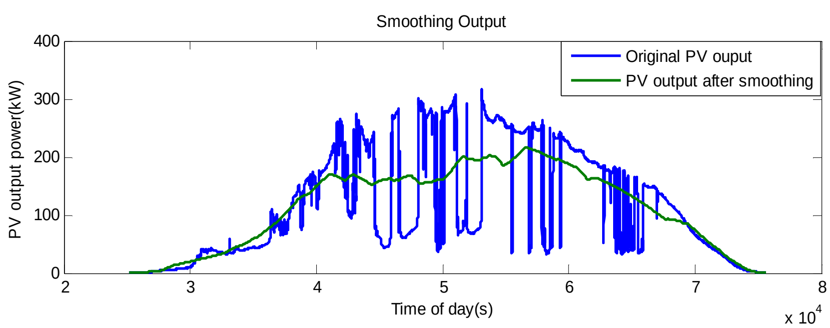

Figure 13 - Example of Modeled Smoothing.

Four different smoothing algorithms are being investigated in the scope of this project: moving average, double moving average, moving median and double moving median. A flowchart for a moving average smoothing algorithm is shown in the Figure 14 below.

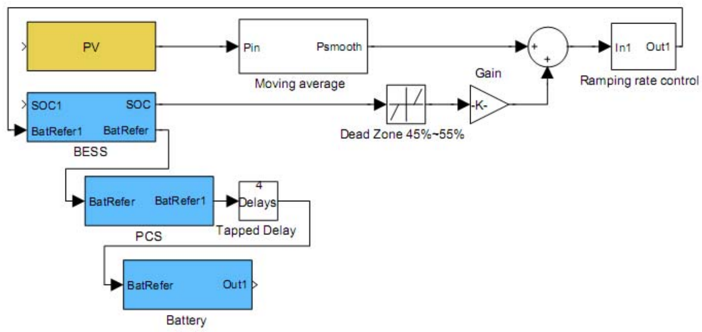

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Figure 14 – Modeled Smoothing

The smoothing battery will see short duration charges and discharges. Its performance is best characterized by its ability to supply rated power (+/-) while maintaining its SoC within upper and lower limits such that when averaged over a 1 hour period its SoC remains at the nominal rating. Several smoothing battery real-time control algorithms have been modeled and are currently being implemented at the test site.

For each of these algorithms, the following parameters are being evaluated as a metric: PV output variance, battery SoC, battery ramping rates, number and depth of battery cycles. A restoring power function is used to slowly drive the battery to the nominal SoC.

The restoring power needs will change dynamically with the change of SoC every second. First, the true restoring power is calculated according to the difference between the real time SoC and a set value. Then available battery capacity is calculated based on battery size, also setting different power rates to offset the difference. If the power rate is too big, it may lead to oscillation of the SoC. If it's too small, it may not offset the difference in a timely fashion. Here, we choose a factor: a, which refers to the weight of restoring power. Different values of : 3, 4, and 5 were iterated for this variable. Secondly, a moving average is used to make the restoring power smooth and not affecting the smoothing operation of the battery.

3.2.1.2 Smoothing Modeling – Moving Average and Low Pass Filters Algorithms - SNL Analysis

This algorithm was designed to be implementable in a real-time controller. The algorithm can switch between moving average (MA) and low-pass filter (LPF) modes.   The operating schema is as follows: A separate battery energy storage system (BESS) commands the battery power level based on a power reference computed by the smoothing algorithm. The smoothing algorithm can be configured to compute the reference signal that the control system is trying to track, either a moving average (MA) of the PV power, or the PV power processed through a low pass filter (LPF). The control system has a supervisory function that tracks the state of charge (SoC) and slowly drives it to a reference SoC, thus maintaining the control range of the battery. To improve the robustness and minimize battery cycling, a dead band function was added to the battery control system. The dead band function will prevent the battery from responding to small excursions that are too small to warrant control action. The control structure has two additional inputs to which the battery can respond. For example, the battery could respond to PV variability, load variability, area control error (ACE) or a combination of the three. Figure 15 below shows the general control algorithm.

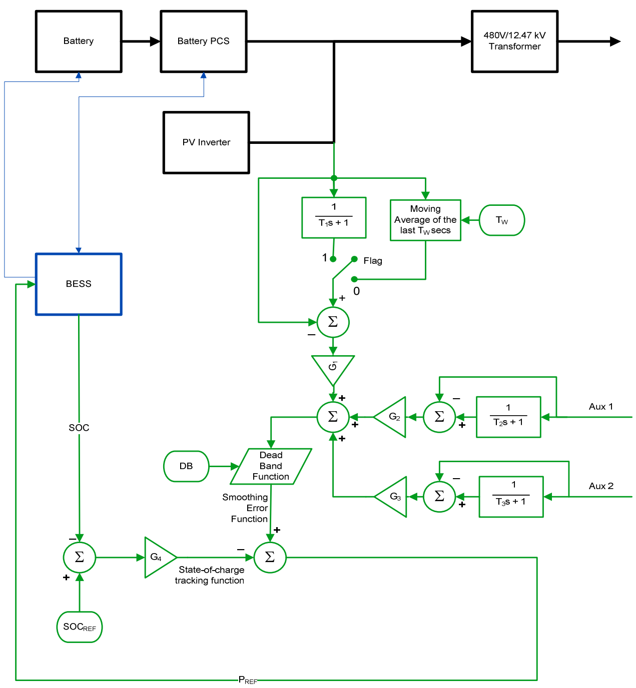

Figure 15 Diagram of PV smoothing control algorithm

The initial condition of the accumulator is set to the desired reference SoC value within the allowable range. For this application, a point in the middle of the range was chosen. A time delay was used as a simple way to represent the response time of the BESS and controls in the power electronic devices. The delay is represented by a time constant TBESS. In this specific application, it is assumed that the delay is on the order of 1 sec. The power rating of the power electronics are modeled with a simple power limiter, set to +/- 500 kW, in this particular case.

The BESS ultimately commands the battery power level based on a power reference computed by the smoothing algorithm. The BESS takes the desired battery power computed by the smoothing algorithm and updates the battery reference power. The battery is assumed to respond to the time constant TBESS. A saturation function is applied to limit the requested battery power to no more than the rating of the power electronics interface (+/-500 kW). The default parameters in Table 1 were derived assuming a control system sampling rate of 1 second, and for the specific application considered during testing.

Symbol	Name	Units	Default Value
TW	PV Moving Average Time Window	Seconds	3600 (1 hour)
T1	PV Low Pass Filter Time Constant	Seconds	3600 (1 hour)
T2	AUX1 (load) Low Pass Filter Time Constant	Seconds	3600 (1 hour)
T3	AUX2 (ACE) Low Pass Filter Time Constant	Seconds	0
Flag	Switch between LPF and MA	0 or 1, 0=use MA, 1=use LPF	1 (use LPF)
G1	PV Smoothing Error Gain	unit less	1 (for 100% compensation)
G2	AUX1 (load) Scaling Factor	unit less	depends on magnitude of AUX1 signal
G3	AUX2 (ACE) Scaling Factor	unit less	Depends on magnitude of AUX2 signal
G4	SoC Tracking Gain	unit less	1000
DB	Dead Band Width	kW	+/- 50 (in models)
SoCREF	Reference State of Charge	unit less (within defined SoC limits)	

Table 3 - Parameters for PV Smoothing Algorithm.

.3.2.2 Shifting Algorithm Modeling

3.2.2.1 Control Strategy of the Shifting Battery System

The Shifting Battery System is nominally operated at a State of Charge (SoC) less than 100%, and is operated above and below the nominal SoC to limits set by the BESS Controller. The difference between the maximum SoC and the minimum SoC is the "Useable Energy". Several algorithms of shifting battery operation have been modeled.

Global Algorithm description:

- Charging:
  - 1st charging period: night time or morning time: from power available during scheduled time till the shift start hour, at max possible charge rate.
  - 2nd charging period: day time: from PV power available during scheduled time till the shift start hour, at max possible charge rate
- Discharging:
  - 1st discharging period: morning time: based on the morning start shift hour, for the morning shift duration
  - 2nd discharging period: evening time: based on the evening start shift hour, for the evening shift duration

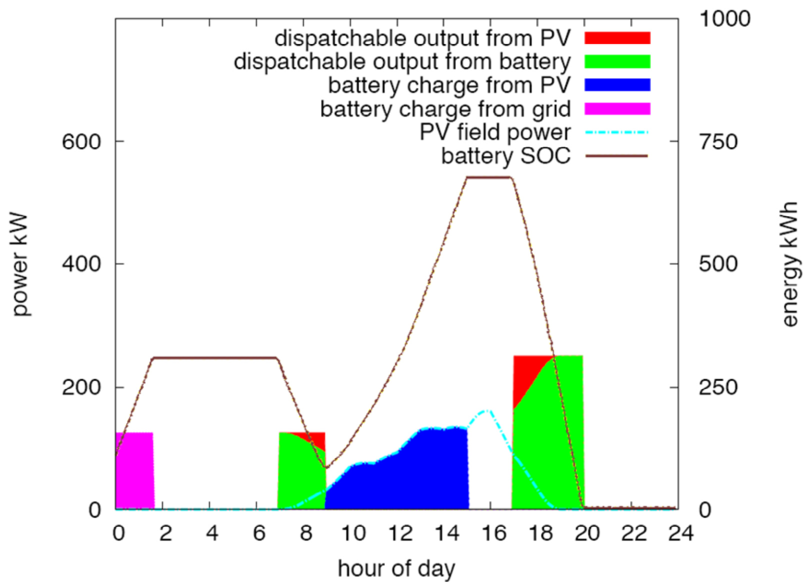

Figure 16 - Global Shifting Algorithm Description

By reducing the “gap” in between the morning and evening shifting blocks, it is possible to merge them into one block (which, in its turn can be shifted in time to evening or any other start time). See Figure 16.

The 4 subsets of this charging algorithm are:

1. Charging from “green electrons” only, i.e. battery charging is only allowed from the PV-generated energy. This scenario will most likely lead to more difficult charging possibilities for early morning charging, before scheduled morning charge.
2. Charging from “any” electrons, i.e. charging from “black” or “coal” electrons at night time is allowed. This scenario is most likely to be most promising for the arbitrage scenario, described in Objective 3.1.(c) above
3. Morning and evening shifting blocks,
4. One longer day-time block (a merger of two smaller morning and evening blocks)

The following represents a preliminary algorithm for shifting and storage planning:

(1) read in firm output request from Operations at suitable chosen interval _t (e.g. 5 min)

(2) read in hourly sky cover forecast from NOAA (weather data)

(3) interpolate hourly sky cover so that it matches _t

(4) calculate or read in solar irradiance for tomorrow's date, at same interval _t

(5) calculate predicted PV array power production

(6) calculate net battery power required at each time step - this is equal to the requested firm power, minus the power that the PV can produce at that time step.

(7) calculate the energy delivered by the battery as a function of time (i.e. at each time step). This is done going forward in time.

(8) calculate the required state of charge of the battery as a function of time which is necessary so that the scheduled battery delivery is met. This is done going back in time, starting at midnight from some desired SoC to be available for the next day.

(9) calculate power available from the PV array. This is total PV power minus any firm power delivery.

(10) calculate the PV charge rate, going forward in time, while simultaneously calculating the battery energy deficit Ed, which is instantaneously equal to the battery charge state and the total energy from the PV charge. The assumption is that we charge the battery using the PV as soon as there is PV power available, and stop when the battery deficit is zero.

(11) charge battery using grid power, at a set rate, until the non-solar battery deficit is zero. The non-solar battery deficit is the difference between the required state of charge and the total solar energy delivered to the battery.

3.2.2.2 Optimization Strategy of the Shifting Battery System

The shifting algorithm is an optimization problem. Some of the important factors to consider are peak load reduction, avoided generation, the system cost and the resulting production of CO_2. The peak load reduction may be the most important factor for shifting. In the high load time, usually the utility needs to use the very expensive peaking power plants to meet the load. The PV power production displacing peaking plants operation can have a very short ROI time for utility. The second factor, avoided generation, is all of power displaced by PV (not only during the peak load periods). The system cost includes the cost of PV and battery storage system. Considering the high cost the battery storage system, we try to use the battery only at the time of much when its most -needed. CO_2 production also needs to be minimized. We will refer to these merit functions as f1, f2, f3 and f4 correspondingly:

$$\mathrm{f}_1 = \text{ feeder peak; } \mathrm{f}_2 = \text{avoided generation}$$
$$\mathrm{f}_3 = \text{cost; } \mathrm{f}_4 = \mathrm{CO}_2 \text{ production}$$

The following parameters x1- x6 show the parameters necessary to optimize peak shifting. They include start and end of shifting, charge and discharge rate for every hour, and the whole battery storage system output.

x_1=starting time ;x_2=ending time;
x_3=charging rate ; x_4=discharging rate;
x_5=System output;

For example, Assume x_1=5am,x_2=9pm;

$x_3,x_4 \in \{-250,250\}$;

$x_5 \in \{-250,750\}$;

Our goal is to optimize the overall merit function:

$F(x) = \sum_{i=1}^{4} \alpha_i f_i(x)$ Equation 1

Where, α_i are the weight factors which determine which of the smaller merit functions f1- f4 are the most important of critical. This optimization is to be performed daily, and will be used by the utility.

3.2.3 Feeder Modeling

Feeder modeling is a key element of the project. The feeder models help validate control algorithm implementation but also serve as a platform for extending the field results to actual high penetration feeders as well as providing a basis for determining status quo equipment requirements which will be used in optimization and cost/benefit analysis.

The project feeder modeling effort utilizes OpenDSS from EPRI and Gridlab-D™ by Pacific Northwest National Lab (PNNL). Both are open source software packages developed mainly to provide tools for modeling distribution systems which are not necessarily balanced.

OpenDSS is a power flow solver which has various capabilities such as fault analysis, harmonic analysis and time based analysis in snap shot, daily or longer term modes. It can be used as a COM object to provide more versatility for other software to be used for further analysis.

Gridlab-D is agent based software which provides numerous analysis and decision making options to the user. In Gridlab-D detailed properties of different types of loads could be modified to make a better match with the real system. Both software tools have the ability to perform time series analysis as opposed to simply solving power flow problem sequentially. This allows for daily, weekly and annual analyses. The process used models of the feeders for both software packages to take better advantage of the individual model capabilities of each and to compare the results as a calibration and verification effort.

PNM data, relating to the feeder's topology, was provided in an unprocessed comma-separated values (CSV) file format. Conductors, transformers, switches, capacitors and other assets are extracted as circuit features into separate files. The data was extracted from PNM's GIS databases, which are not designed to provide standard output to be fed directly into the modeling software. Therefore, the circuit's information had to be translated from CSV files to an interpretable script. The very first step was to develop translator software. Translator applications were developed for both software packages that are capable of building the basic model of each feeder under study.

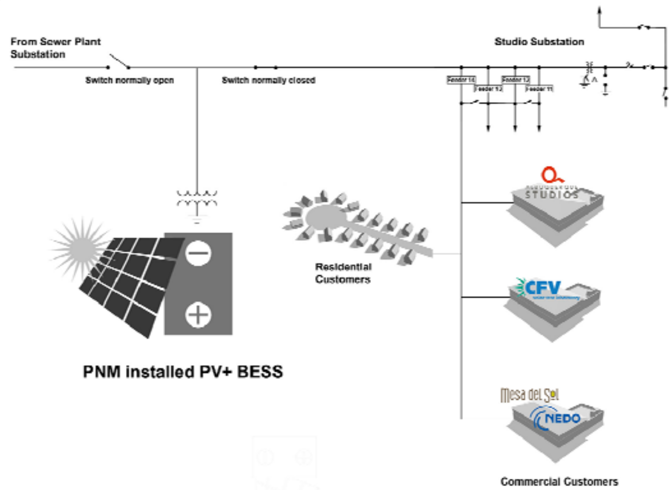

Figure 17 - PNM Smart Grid Demonstration Project – highlighting the associated feeders

Figure 17 above details the layout of the system with respect to feeders served. SewerPlant14 and Studio14 are two of the distribution feeders of the city of Albuquerque, New Mexico serving the site and being subsequently modeled. Those feeders were expected to have different characteristics as they connect to the Smart Grid Demonstration site, due to :

- SewerPlant14 serves a fully developed residential/commercial area while Studio14 is still under development.
- PNM PV system could be connected to SewerPlant14's end point while it could be connected to the beginning of Studio14

A mixed number of residential and commercial customers comprise the load connected to SewerPlant14 feeder. Due to limited information about each individual customer's consumption behavior, an exact load model was not able to be determined for each customer. However, load seen at the substation, but not individual loads was of primary interest. Therefore it was concluded that total load seen at the substation transformer could be a good base case for building load shapes that could be expected to be seen at each customer's service drop. This feeder's total demand and energy consumption, recorded every 15 minutes, was the primary data to develop load models. Feeder's load shape was generated by normalizing 15-minutes demand data based on the feeder's nominal rating and is shown in Fig. 18..

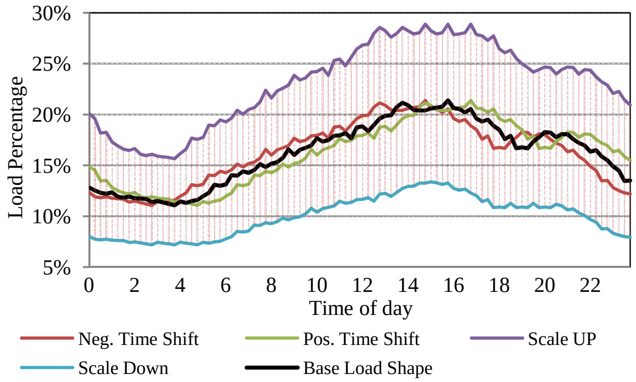

Fig. 18. SewerPlant14 Base Load Shape (Thursday, Sep., 2, 2010)

One heuristic approach for approximating each customer's load shape was to shift the base load shape randomly for a limited time, while randomly changing the load shape's magnitude within a certain percentage of the base load shape, i.e. if basic load percentage at any given time t was $l_b(t)$ load percentage for customer i at that time would be:

$\boldsymbol{l_i(t) = l_b(t + \alpha_i(t)).\beta_i(t)}$ Equation 2

$\boldsymbol{\alpha_i(t) = G1(\Delta)_i}$ Equation 3

$\boldsymbol{\beta_i(t) = G2(\sigma, t)_i}$ Equation 4

Visual representation of equation resulted in upper and lower boundaries which are shown in Fig. 18. Upper and lower bounds show the maximum and minimum possible load percentages for the each load while any point in the hashed area is a possible point for a load shape. Δ and σ are distribution function's parameters.

In order to properly analyze the feeder's behavior with required resolution, the load shapes must have an equal or higher resolution than metered data. Feeder demand data, from the existing SCADA system, was recorded every 15 minutes, while at least 1-minute interval data was desired for analysis. Missing data points were found by extrapolation between available load data points, assuming that feeder load has a smooth transition between every 2 consecutive points. Finer time steps could easily be generated when necessary but higher resolution must be balanced with the required processing burden. In the future, shorter step analysis may be needed for generation intermittency effects studies.

Different levels of scaling and time shifting has been studied. In Figure 19, a randomly selected customer's load shape after ±1 hour time shift and ±65% magnitude scaling is presented.

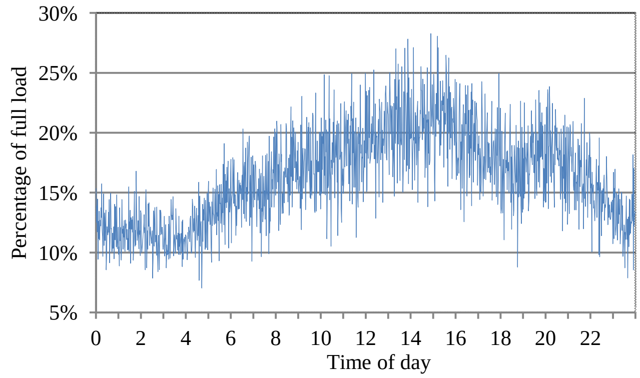

Figure 19 - Generated load shape for a random customer (scaled to service transformer's rating)

Adding Loads to the Model

Having developed those load shapes, the next step was to add loads to the model. Loads, associated with a load shape, represent customers in the model. For that purpose, PNM has provided a detailed list of premises, which was used to define load objects in the models. Each premise came with an identifier plus the identity of the transformer, supplying that load. Although adding loads to the models looked to be a trivial job, because of many constraints, it was almost impossible to assign nominal load capacity to each customer. Service nominal amperage (capacity) was known but normally that value could give a sense of maximum load, not actual values. An allocation method is used to find each customer's allocated load versus its supplying transformer's rating. The allocation procedure was performed by OpenDSS, which has a built-in function which could optimize load multipliers to meet a specific load at specific zone. All loads were allocated with respect to maximum feeder capacity to serve .

$$\boldsymbol{Feeder\ Nominal\ Capacity} = \sum_{i=1}^{n} \boldsymbol{m_i.T_i} + \boldsymbol{Full\ Load\ Loss} \qquad \text{Equation 5}$$

$m_i: load\ multiplier\ for\ customer\ i$

$T_i: nominal\ transformer\ rating\ feeding\ customer\ i$

According to Figure 19 the developed load shape has a high frequency of variation which is not a realistic assumption for loads expected at the distribution level. Loads usually don't exhibit such a high frequency of variations. For this reason, a metric was defined to depict average time duration between two consecutive changes in the load level and named it load response times (LRT). Several case studies to see effects of different LRTs on the cumulative load seen at the feeder source were conducted.

3.2.4 PV Ramp Rate Analysis Methodology

3.2.4.1 Methodology Overview

For this analysis, ramp rate is defined as the instantaneous rate of change in power. In the case of a solar array, the ramp rate (in power/time) can be taken from either total array output power (in W) or nominalized to effective array area by using irradiance (in W/m2). For this analysis and applicability to solar arrays of all sizes, ramp rates will be expressed in W/m2/s.

3.2.4.2 Statistical Comparison of Ramp Rate Analysis

In order to gauge the effectiveness of the smoothing battery it is necessary to understand the ramp rates produced by the PV system and the effect of varied input signals and corresponding output levels applied by the smoothing battery.

The first question that needs to be addressed is a working definition of ramp rate. These can range from a simple differencing of consecutive measurements to, e.g., an averaging of these differences over some *a priori* specified time range. The approach taken is to use smoothing splines that interpolate the data first. By controlling a single parameter in the spline definition the degree of smoothing of the raw data can vary from minimal (the data is perfectly interpolated, so there is no smoothing) to maximal (a linear regression line is fit to the day's measurements). Taking the derivatives of the splines at specified points will give an estimate of the ramp rate. Comparison of this method to the simple differencing method shows that they give similar results when the splines are not smoothed. However, being able to conveniently control the degree of smoothing is a distinct advantage of using splines.

When considering the effects of various independent variables on smoothing efficacy the first question to answer is how to measure the overall level of smoothing. One possible measure is the largest ramp rate observed both before and after smoothing. However this would place all of the analysis on a single, potentially isolated, event and would likely not give a good picture of what occurred over the whole day.

The measurements being compared are the magnitudes of all of the observed daily ramp rates before smoothing and after smoothing. Empirical Cumulative Distribution Functions (ECDFs) are then formed for each of these collections. These are denoted as ECDFs as $ECDF_{PV}$ for the ramp rates observed with the PV meter measurements and $ECDF_{PM}$ for the ramp rates observed with the Primary Meter measurements. Given these two ECDFs the final scalar value we find is the area between 1 and $ECDF_{PM}$ as a percentage of the area between 1 and $ECDF_{PV}$:

$$A = \frac{\int_0^\infty (1 - ECDF_{PM})dr}{\int_0^\infty (1 - ECDF_{PV})dr} \quad \text{Equation 6}$$

This is a dimensionless quantity that helps to compare the effects of smoothing while cancelling out, to some extent, variations from day to day in the $ECDF_{PV}$. A value of *A* close to 0 indicates good performance on smoothing. As *A* nears or exceeds 1 the smoothing was less effective for that day.

With *A* as the dependent variable the following are the independent variables considered:

- Smoothing control source (a categorical independent variable)
- Cloud cover (an ordinal or a ratio independent variable)
- Increment of battery capacity (an ordinal or a ratio independent variable)
- Potentially season (an categorical variable)

Note that the type of variable for each independent variable is included. For cloud cover and increment of battery capacity we will likely treat these as ratio variables. Seasonality effects will initially be ignored. Other independent variables may be included as appropriate.

The dependent variable *A* is itself a ratio variable. By ignoring things like smoothing source then a standard regression analysis would suffice. If the ratio independent variables can be ignored then a standard ANOVA (ANalysis Of VAriance) would suffice. Neither of these is the case however, so the appropriate statistical tool is ANCOVA (ANalysis of COVAriance). This allows us to investigate the effects of both categorical and ratio independent variables on a ratio dependent variable. This is initial test that will is being pursued to investigate smoothing.

Ultimately the question of what is a good definition of ramp rate is a question of how to effectively estimate the derivative of a function. The use of splines for this is tentative though well motivated. The area of numerical differentiation is a subject with a long history. These various procedures will be investigated. Downstream efforts are described further in Section 7

3.2.4.3 Ramp Rate Specific Methodology

To investigate ramp rate behavior and interpretation, two different numerical methods of varying order of accuracy were tested using a known function for which a derivative is calculated. This was then used to find the numerical derivatives' error depending on sample rate (time interval). The methods are then used to calculate ramp rates using theoretical clear-day fixed-plate collector irradiance data to establish a typical clear-day ramp rate distribution. Finally, historical irradiance data were purposefully selected for cloudy days to examine the effects of high variability.

3.2.5 Correlation of Percent Cloud Cover Weather Forecast to Actual Irradiance

It is important to understand the accuracy of the weather forecast used by the shifting algorithm. The goal of this initial analysis is to compare measured irradiance from the Prosperity Project's solar array at Mesa del Sol in Albuquerque, New Mexico to predicted irradiance. Predictions are based on known methods for calculating clear day terrestrial irradiance in combination with National Weather Service (NWS) percent cloud cover predictions. First, the direct irradiance on a south-facing surface with 25˚ tilt was calculated. The model was to calculate the global irradiance for clear-day conditions in Albuquerque, New Mexico.

A computer program was written in modules which were assembled after individual testing for accuracy. These modules included data loading and organizing, curve fit or interpolating, and theoretical annual irradiance calculation codes. The code was designed for varying sample rates and mathematical anomalies such as infinite or undefined terms. While the code is customized to the Mesa del Sol site, the underlying method could be reproduced for other locations and conditions.

The measured data loading and organizing code takes advantage of MATLAB's built-in Excel data loading function. Providing the layout of data is known (i.e. which columns contain what), the data are loaded into the workspace in matrix form. The irradiance data are saved in a matrix of size "day of year" X "samples per day" through a series of loops and filters. For example, the tested data had a sample rate of every minute which yielded a [365 X 1440] matrix.

Memory locations associated with all days where no data were recorded are set to zero to provide easy filtering later. A visual representation of irradiance data recorded for the month of September 2011 is shown in Figure 20. It is apparent that the typical arc of a clear day's irradiance is disrupted by clouds. Clear days maintain a relatively smooth curve and cloudy days cause a jagged profile.

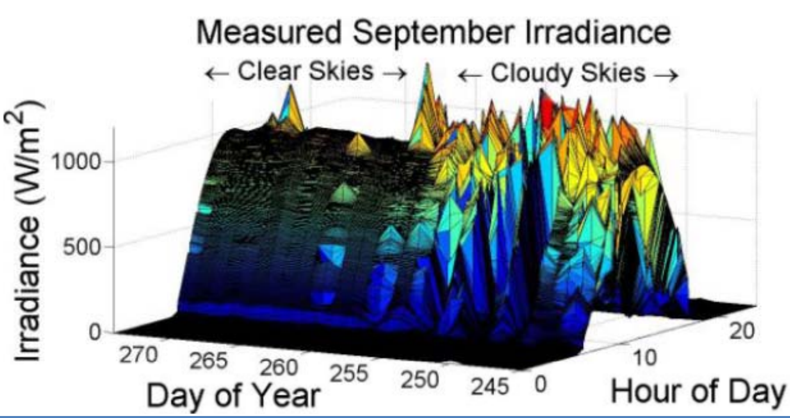

Figure 20 - Measured Irradiance Data (Sept. 2011); displays variability in power due to clouds

A sliding average was taken for this data to provide easier comparison to the prediction method. The same data shown in Figure 20 then appears below in Figure 21

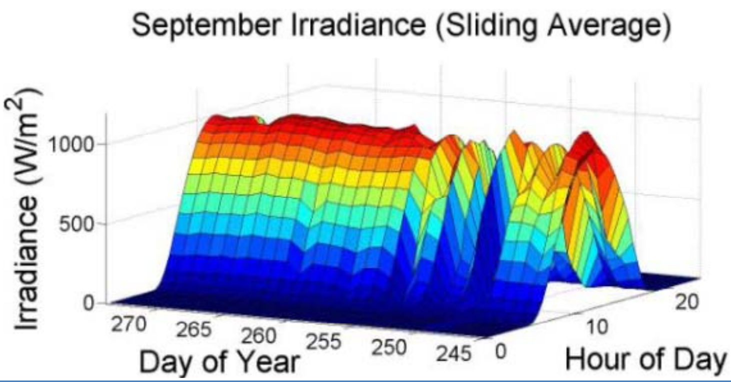

Figure 21 - Average Sept. 2011 Irradiance Data; used to compare to prediction

3.3. Methodologies for Determining Grid Impacts and Benefits

As the project progresses and data accumulates, optimization analysis will be required to determine the optimal smoothing battery size as well as the optimal shifting output strategy.

3.3.1 Smoothing Optimization

In order to determine an adequate amount of smoothing battery capacity needed, an optimization routine will look at status quo distribution equipment normally used to mitigate PV intermittency. The feeder models will be used to simulate high penetration scenarios calibrated to actual operation. The target will be the highest avoided cost of status quo equipment needed to mitigate effects of high penetration PV intermittency contrasted to the lowest amount of smoothing battery capacity. The methodology will involve statistically comparing the ramp rate mitigation from various capacities and settings (Test Plan 1), determining the best combination and then modeling this in a high penetration feeder. Then a economic comparison will be made to determine monetized benefits.

3.3.2 Shifting Optimization

Firming –Utilizing the shifting batteries to produce a known quantity of energy based on day ahead forecasts is labeled in this project as firming. The objective here is to create a known rectangular shape of energy output from the combination of the shifting batteries and the PV resource with a known start and end time and a know output. Based on the discussions with PNMs Wholesale Marketing Department, it was established that the PNM's high demand times can be categorized as following segments in time versus seasons:

Nov: HE5-8 and 18-21

Dec-Feb: HE6-9 and 18-21

Mar: HE 5-8 and 18-21

April -October: HE 14-18

(HE = hour ending)

Optimization will involve investigating different known shapes, see Figure 22 below, to determine over a course of time which approach eliminates or offsets the most peaking period energy. The cost benefit analysis will then calculate an associated LCOE for the firming battery compared to a proxy gas peaking unit.

Peak Shaving - Utilizing the shifting batteries to offset loads at a substation or feeder is labeled in this project as peak shaving. A similar approach will be utilized to study the effects of peak shaving. The difference will lie in offsetting upgrade costs in a high penetration PV modeled for a loaded feeder. Here the costs of the deferred upgrade will be compared to the cost of the shifting batteries.

3.3.3 Shifting Control Automation

Control of the shifting batteries is based on the shifting algorithm (mentioned above) which resides in the Advanced Calculation Engine (OSI ACE). The approach to automation of the shifting algorithm involves the following steps:

1. Develop code from UNM modeling efforts targeting the timeframe and energy delivery requirements dictated by PNM WSM.
2. Test this code in UNM models for SoC adherence via UNM OSI ACE
3. Develop a scheduled list of output commands based on a clear day (no clouds)
    a. Summer schedule – target flat top production 2pm to 6pm (see Figure 22 below – initial output target)
    b. Winter schedule – target flat top production 6am- 10am and 4pm to 8pm
4. Manually schedule input into PNM OSI ACE
5. Develop an automated version that

   a. Takes % cloud cover from NWS web page
   b. Calculates next day PV energy available
   c. Calculates time and level of shifting battery charge and discharge based on summer or winter schedule for initial firming target shape
   d. Automatically instructs BESS
6. Modify target shape for Test Plan 2 (enhanced), 3 and 5 – see Figure 22
   a. Optimization effort based on delivery maximum kWh
   b. Optimization based on peak shaving signal from substation or feeder monitor
7. Enhance the inputs to potentially include
   a. Other solar PV forecasts
   b. WSM Pricing
   c. System, substation and feeder loads
   d. Carbon pricing/penalties
8. Enhance the algorithm to optimize production from shifting battery based on the above inputs

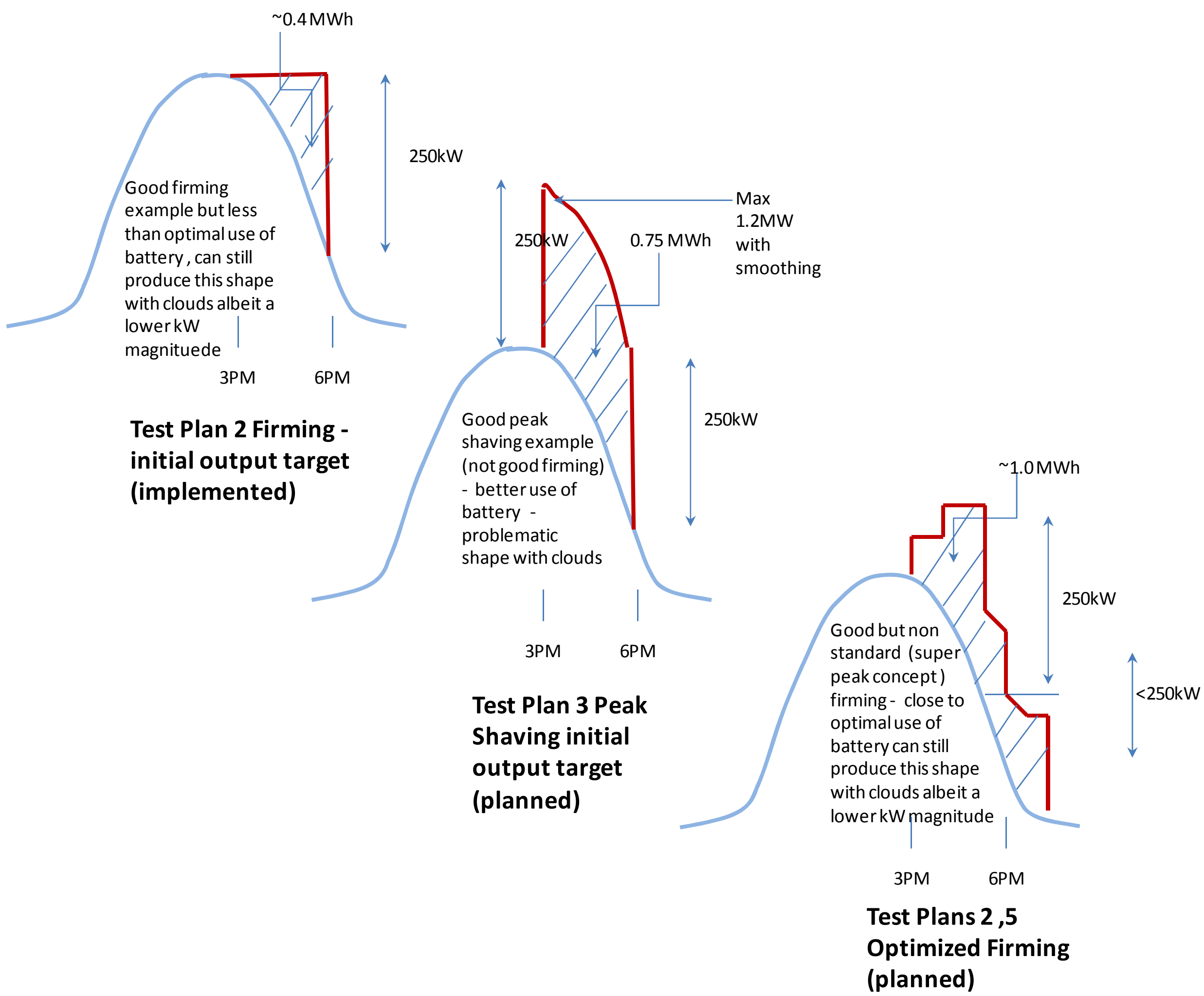

Figure 22 Firming and Peak Shaving Target Shapes

The maturation of the shifting algorithm can be represented in Smart Grid terms by targeting the evolution of manual commands to a distributed resource to an back office automated platform that self feeds external inputs, calculates optimized production schedules and instructs a distributed resource. Figure 23 below charts the process of evolution to a Distribution Management System (DMS). Key elements of the plan include starting from the manual implementation (achieved), implementing an automated version (achieved), automating external variable inputs including

- NWS Forecast
- Other PV Forecasts

- Wholesale Pricing Information/Forecasts
- Load Forecasts
- Carbon Pricing

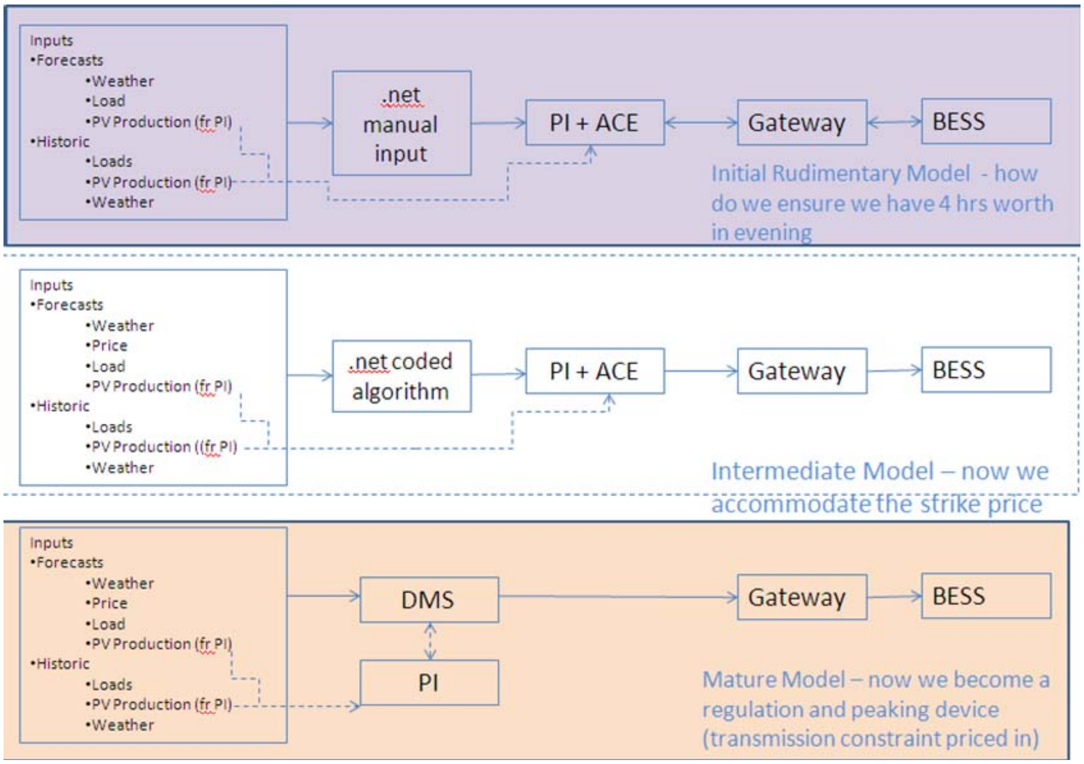

Figure 23 DMS Conceptual Evolution

4 Technology Performance Results

4.1 Smoothing Field Results

The smoothing test has been conducted via Test Plan 1 (see Section 3 Appendix B) utilizing the variable sets in Table 4.

			Test Plan 1 Smoothing Control Source							
test label	period	Feeder Configuration	irradiance sensor	primary meter	PV Meter	ACE from PNM	Increment of Battery Capacity	Maximum Duration (days)	Start Date	End Date
1BPV0.1	**1**	B			**x**		10%	10	10/31/2011	11/10/2011
1BPV0.4	**1**	B			**x**		40%	10	11/16/2011	11/26/2011
1BPV0.7	**1**	B			**x**		70%	10	12/9/2011	12/28/2011
1BPV1	**1**	B			**x**		100%	10	1/3/2012	1/13/2012
2BIRRA0.4	**2**	B	**averaged**				40%	20	1/19/2012	2/8/2012
2BIRRA0.7	**2**	B	**averaged**				70%	15	2/14/2012	2/29/2012
2BIRRA1	**2**	B	**averaged**				100%	18	3/6/2012	3/24/2012
3BIRRSW0.4	**3**	B	**sw corner**				40%	15	3/30/2012	4/14/2012
3BIRRSW0.7	**3**	B	**sw corner**				70%	15	4/20/2012	5/5/2012
3BIRRSW1	**3**	B	**sw corner**				100%	10	5/14/2012	5/24/2012
4BPV0.6	**4**	B			**x**		60%	10	5/30/2012	6/9/2012
4BPV0.8	**4**	B			**x**		80%	10	6/15/2012	6/25/2012
4BPV1	**4**	B			**x**		100%	10	7/1/2012	7/11/2012
5BPV0.6	**5**	B			**x**		60%	10	7/17/2012	7/27/2012

Table 4 - Test Plan 1 Test Configuration

To date the control signal inputs have consisted of the PV Meter, an average of the 5 irradiance field sensors (1 on each corner and 1 in the middle of the array) and the SW corner irradiance sensor. The feeder configuration has remained in Beginning of Feeder. The following graphs show the Primary Meter (red), PV Meter (blue) and the Smoothing Battery output (yellow) . The % battery capacity refers to the % gain used in variable in the G1 variable for the control algorithm (see Table 5 below).

For the following figures

- Solar PV Meter data appears in blue
- Primary (Net System) Meter data appears in red
- Battery Meter data appears in yellow

Figure 24 displays four consecutive days of early operation in November 2011. With the input gain set at 0.1 effectively 10% of the battery capacity was used. Little to no smoothing effect are evident on the first and fourth days of the data set where cloud cover was great enough to induce the smoothing. No smoothing was required on the second and third days as no cloud cover was present.

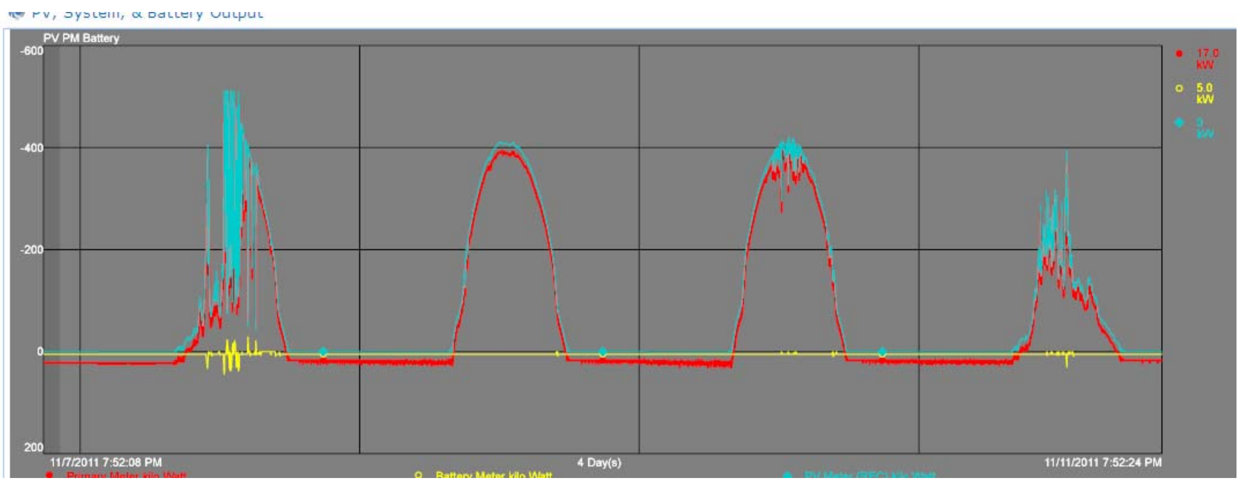

Figure 24 - System Output 1BPV0.1 – 10% of PV Meter

When the System was run at 100% of the PV Meter as an input signal, Figure 25, much more smoothing is apparent. The performance of the smoothing is even more evident in a magnified view of the first day of the data set, 1/15/12, shown in Figure 26. Some spiking occurred because of late response of the smoothing battery, as shown in a magnified view in Figure 27 the magnified view of second day of the data set. This was caused by latency issues from a variety of sources and was resolved, see discussion below.

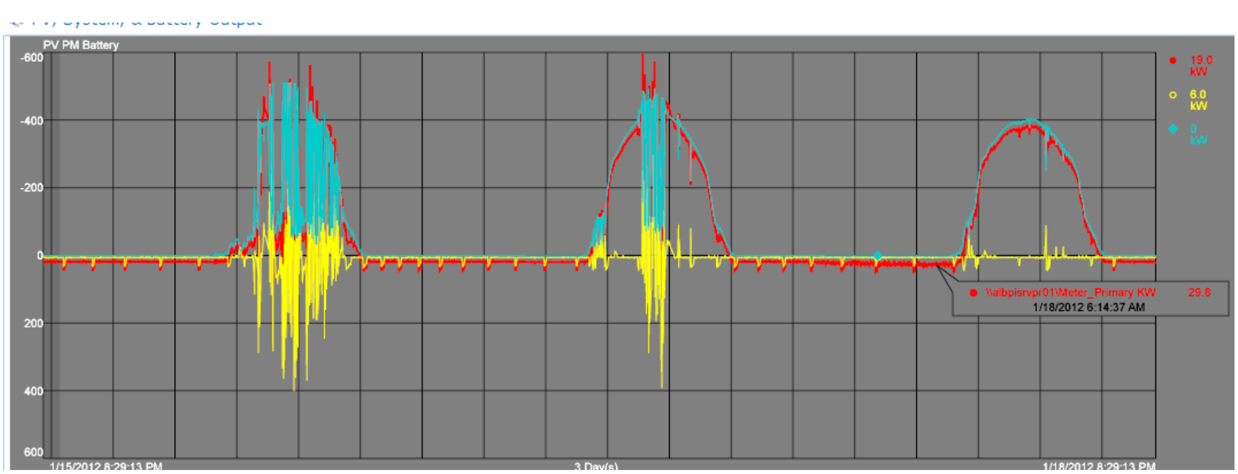

Figure 25 - 1BPV1 100% of PV Meter

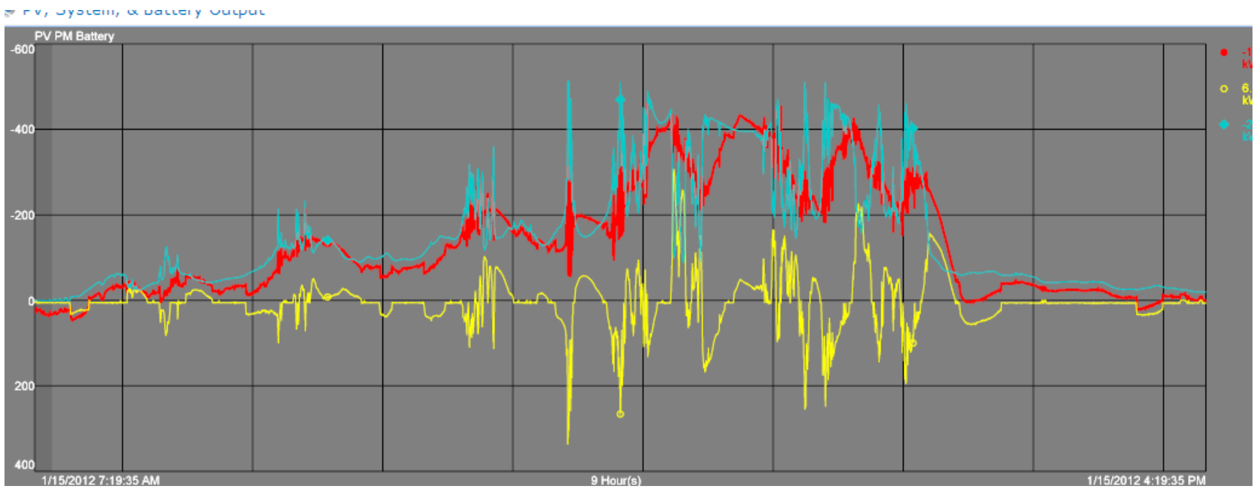

Figure 26 – 1BPV1 - Magnified view of 1/15/12 Smoothing

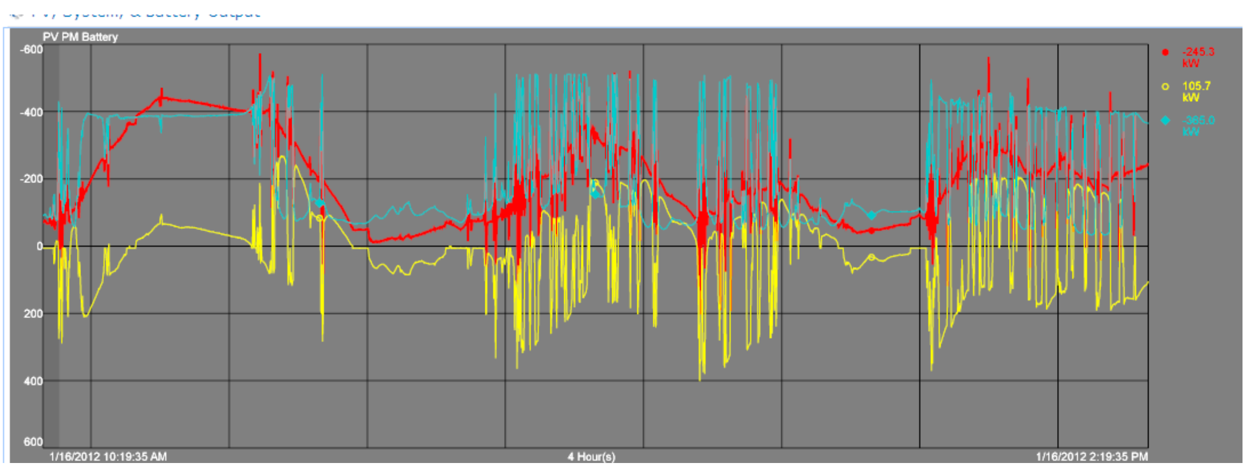

Figure 27 - 1BPV1 - Magnified View of 1/16/12 Smoothing

A subsequent subset of Test Plan 1 utilized the average of the five irradiance sensors as inputs. Figures 5-9 below show a variety of results utilizing various gains of the irradiance sensor average. Of significance is Figure 32 which shows significant spikes from the battery 6/8/2012. The cause of this unwanted effect and subsequent solution is discussed below.

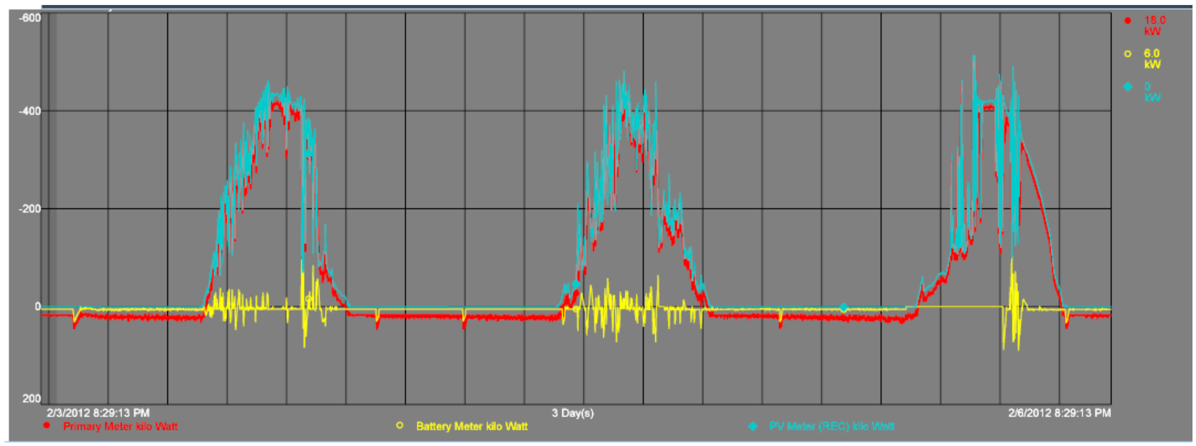

Figure 28 - 1 BIRRA0.4 - 40% of Irradiance Sensor

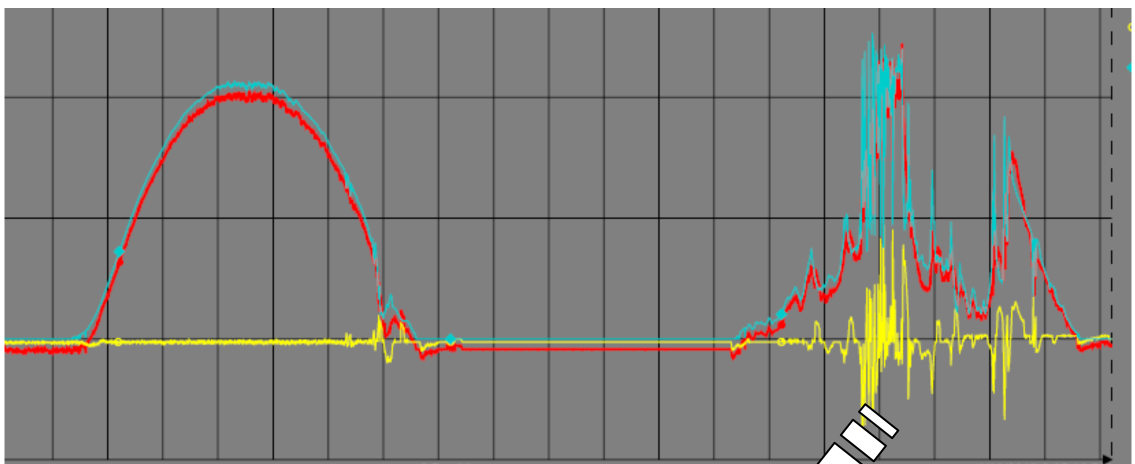

Figure 29 1BIRRA0.7

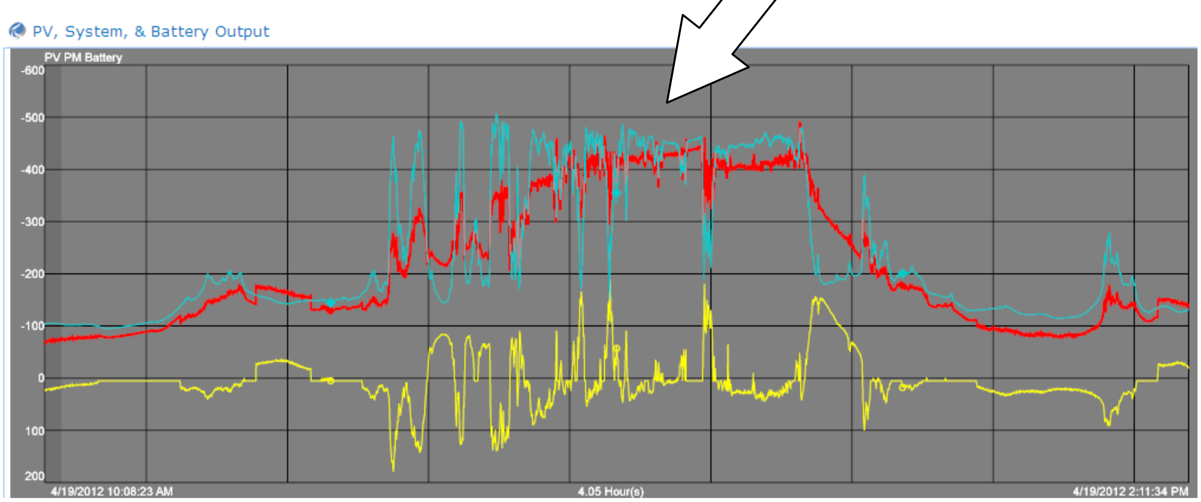

Figure 30 1BIRR0.7 magnified

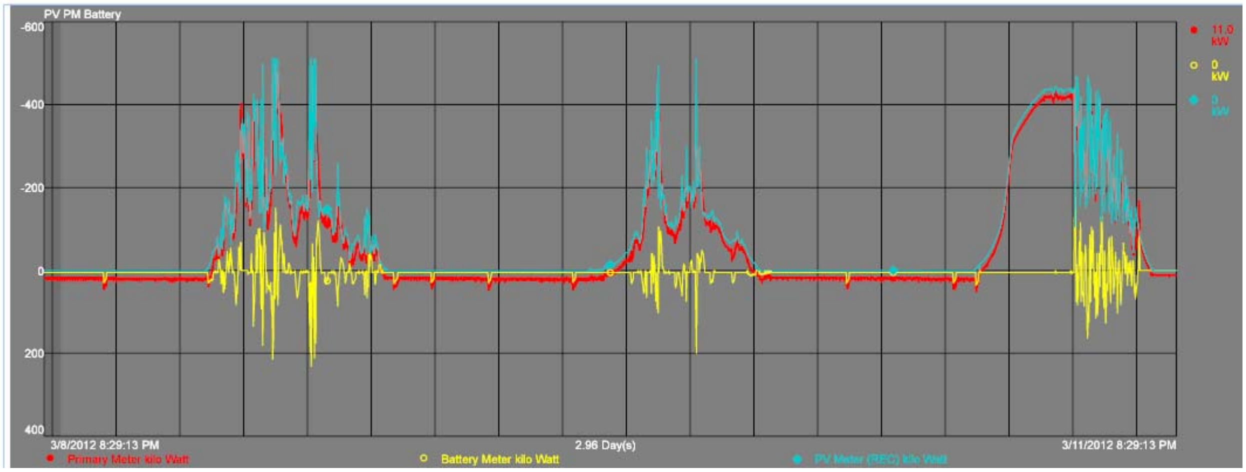

Figure 31 2BIRRA1 - 100% of Average of Irradiance Sensors

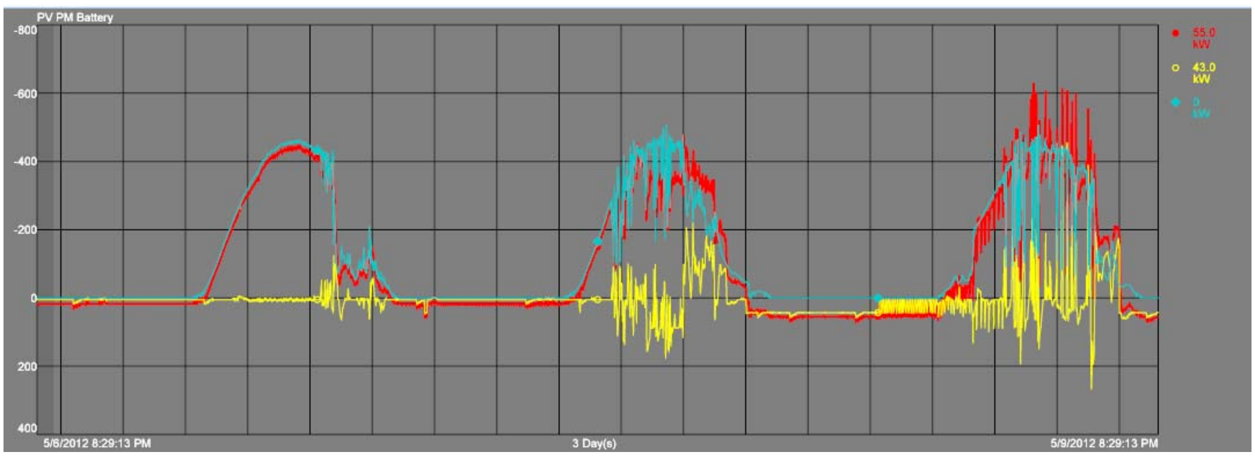

Figure 32 - 3BIRRSW0.7 - 70% of SW Irradiance Sensor

4.1.1 Key Observations – Smoothing

Latency delays in the PCS and BESS software cause the smoothing battery to react too late to severe intermittency. This resulted in upward spikes at the Primary Meter since the battery response happened after the cloud passed and the PV output recovered. The latency was determined by looking at the DAQ gateway. The signal in the DAQ determined control signals are sent a maximum of 37ms, resulting in tuning dead bands in the inverter and battery control system.

Control source Input - Irradiance Sensors

Irradiance values are scanned from Micrologger:
"**12:12:57,625**", "-07:00", Master Protocols/Modicon (MODBUS)/02: CR3000/Scan Rx Data"

Irradiance values are received by the BESS: 6 Irradiance values are being instantaneous except for the nw & ne irradiance, but 1ms later.
"12:12:57,625", /Master Protocols/Modicon (MODBUS)/01: BESS/Control", DIRECT EXECUTE on point "BESS_IRR_met" by "BESS Control", value: 775.862."
"12:12:57,625", /Master Protocols/Modicon (MODBUS)/01: BESS/Control", DIRECT EXECUTE on point "BESS_IRR_sw" by "Automation Functions Server/02: BESS Control", value: 1077.053."
"12:12:57,625", /Master Protocols/Modicon (MODBUS)/01: BESS/Control", DIRECT EXECUTE on point "BESS_IRR_se" by "Automation Functions Server/02: BESS Control", value: 1085.475."
"12:12:57,625", /Master Protocols/Modicon (MODBUS)/01: BESS/Control", DIRECT EXECUTE on point "BESS_IRR_cent" by "Automation Functions Server/02: BESS Control", value: 1073.413."
"12:12:57,626", /Master Protocols/Modicon (MODBUS)/01: BESS/Control", DIRECT EXECUTE on point "BESS_IRR_nw" by "Automation Functions Server/02: BESS Control", value: 1075.924."
"12:12:57,626", /Master Protocols/Modicon (MODBUS)/01: BESS/Control", DIRECT EXECUTE on point "BESS_IRR_ne" by "Automation Functions Server/02: BESS Control", value: 1087.447."

Irradiance values are stored in PI: Irradiance are being recorded in PI 894ms later.
"12:12:58,520", /Slave Protocols/DNP3/01: PI/Objects Reported", " Analog Input Point 00009 = 1073 "
"12:12:58,520", /Slave Protocols/DNP3/01: PI/Objects Reported", " Analog Input Point 00011 = 776 "
"12:12:58,520", /Slave Protocols/DNP3/01: PI/Objects Reported", " Analog Input Point 00012 = 1087"
"12:12:58,520", /Slave Protocols/DNP3/01: PI/Objects Reported", " Analog Input Point 00014 = 1076"
"12:12:58,520", /Slave Protocols/DNP3/01: PI/Objects Reported", " Analog Input Point 00017 = 1085"
"12:12:58,520", /Slave Protocols/DNP3/01: PI/Objects Reported", " Analog Input Point 00019 = 1077 "

Control source Input - Irradiance PV Meter

PV Value from Meter: signal stayed constant at 65kw (for two seconds)
"**16:27:15,279**", Master Protocols/DNP3/02: 480V xfmr PV meter/Objects Reported", "Analog Input Point 00015 = -66 "

PV value from Meter received by BESS: BESS received the value 37ms later
"16:27:15,316", /Master Protocols/Modicon (MODBUS)/01: BESS/Control", "DIRECT EXECUTE (Simulated confirmation) on point "BESS_PV_inverter_power" by "Automation Functions Server/02: BESS Control", value: -66.000."

PV Signal from Meter: PI received the same point 279ms from when the PV detected the change
"16:27:15,557", /Slave Protocols/DNP3/01: PI/Objects Reported", "Analog Input Point 00134 = -66"

- PV Meter trace speed of signal at 37mS from PV meter to BESS (279mS from meter to PI database)
- Irradiance Sensor trace speed is at 0-2mS (faster because of no protocol translation in Gateway)

Figure 33 -Gateway Screen Shot of Signal Speed Check

- Corresponding software revisions were mapped to the test plan to allow for configuration alignment to the data set
- The 10% setting produced no discernible effect, however the 40%, 70% and 100% settings had noticeable effects on smoothing
- The effects have be to analyzed from a strict statistical analysis to screen out variance from clouds, seasonality, ambient temperature and configuration settings – see discussion below on statistical methodology results
- The data must be optimized against PNM status quo solutions to smoothing and high penetration PV intermittency in order to understand and establish an adequate level of smoothing (how much smoothing is enough?)
- OpenDSS and GridLAB models will need to be relied upon to model high penetration PV feeder effects – the Studio feeder in reality doesn't have enough penetration to present a problem
- The irradiance sensors should not be used as an input especially when PV production is close to inverter capacity (shoulder months – especially May). The irradiance may drive upward but the PV output is limited by inverter capacity. The smoothing battery with

irradiance as a control signal input ,may, in this case, over respond and cause an upward spike at the Primary Meter
- Ripple effects were introduced to the Primary meter during hotter weather due to battery and PCS air conditioning units cycling. The ripple presents a challenge in analyzing PV vs smoothed output at the Primary Meter

4.2 Shifting Field Results

The Shifting Algorithm was initially tested in UNM's PI OSI ACE environment, with beta testing complete in January 2012. The first field tests of the algorithm assumed the following

- Clear Day Prediction was used assuming no clouds. The algorithm uses the date to calculate a PV production curve based on a clear day.
- The Hour Ending (HE) delivery is scheduled as follows to align with PNM WSM Peaking requirements:

  Nov: HE5-8 & HE18-21

  Dec-Feb: HE6-9 & HE18-21

  Mar: HE5-8 & HE18-21

  April-October HE13-20

The output of the model appears as follows, in Figure 34

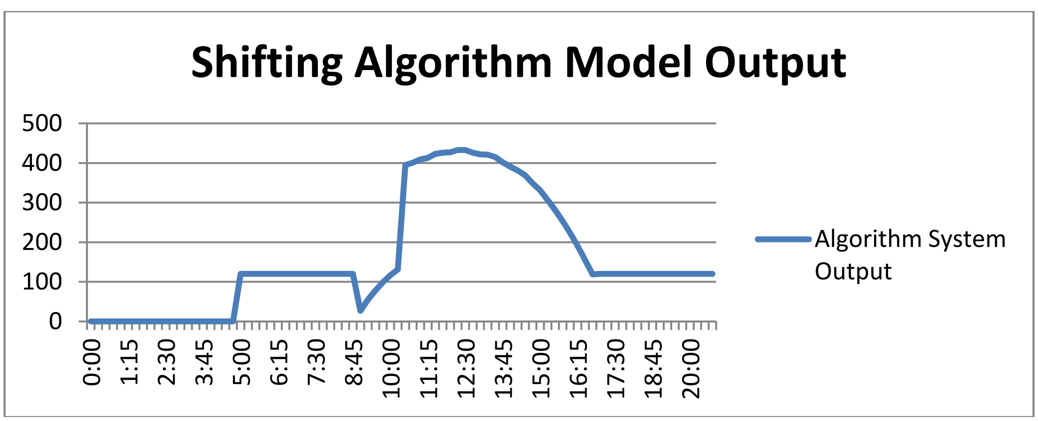

Figure 34 - Shifting Model Output

The numerical outputs were then manually entered every 30 minutes into PNM OSI ACE to produce the following field results:

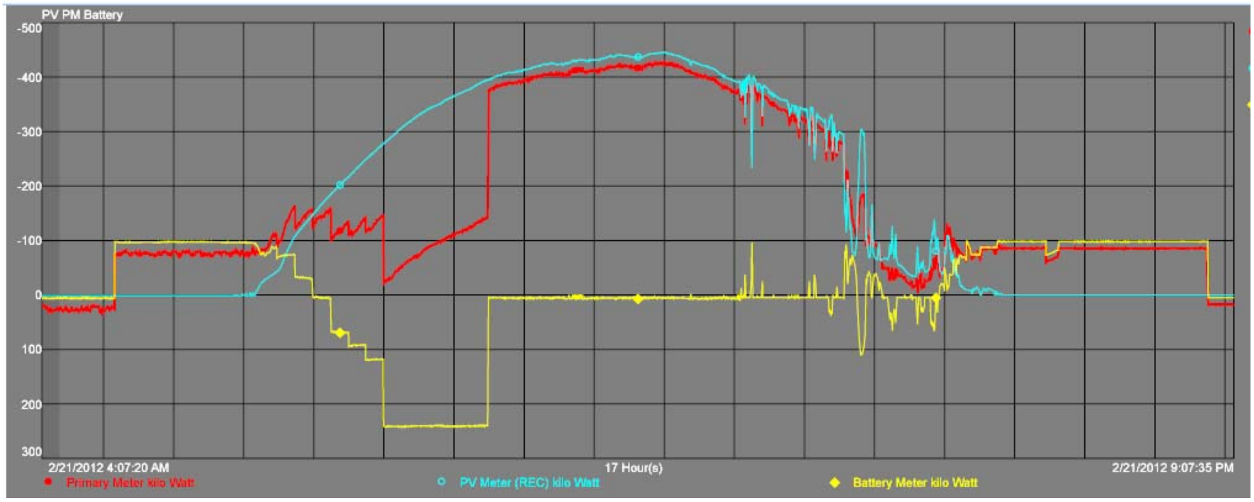

Figure 35 - First Iteration - Manual Shifting – Winter Schedule

The firming production from the battery began at 5am and it can be seen graphically in Figure 35. When the PV production started later in the morning the algorithm didn't correctly adjust for the PV increase, resulting in an increase in the Primary Meter output rather than a desired flat production. Additionally the time steps associated with manual inputs were too granular.

The algorithm was refined to accommodate 1 minute instruction to the BESS from the OSI ACE and modified to better account for the PV production curve. With validation of the algorithm attempts were then made to transfer the operating code from UNM's OSI ACE to PNM's ACE_1. Issues arose in the transfer that turned out to be related to version issues (UNM developed the algorithm in a higher version than PNM was operating). Once these software issues were resolved the automated version was placed on PNM's OSI ACE. Figure 36 shows a much better flat top production at the Primary Meter.

This is significant in that it demonstrated the ability of the storage system to produce a rectangular shaped energy output, from external utility based commands, by storing sinusoidal shaped PV and producing output on top of the PV output.

Note the ragged nature of the Primary Meter readings in the summer months is due to the cycling of the battery container air conditioner units. The ripple presents an issue for statistical analysis of ramp rate mitigation and mitigation plans will be developed to address this (see Future Plans Section). Figure 37 shows automated shifting over successive days.

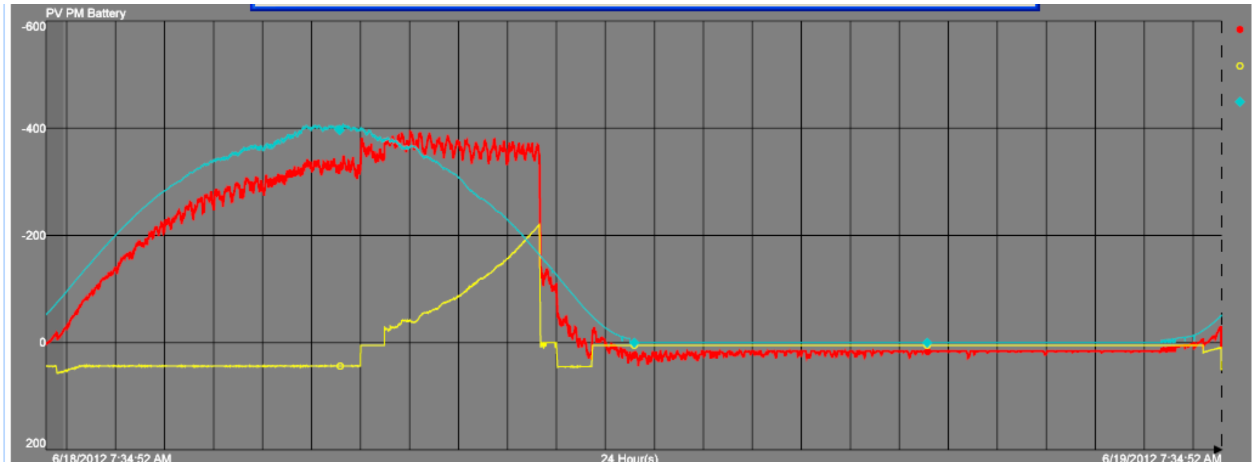

Figure 36 - V1.8 - Automated Shifting – Summer Schedule

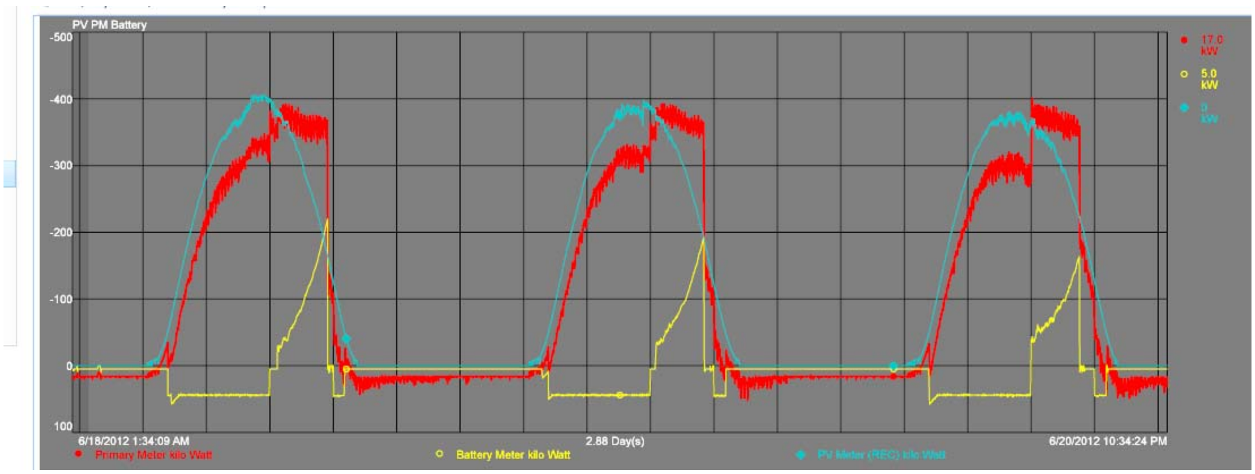

Figure 37 - Automated Shifting Summer Schedule - Multiple Days

The following, Figure 38 and Figure 39, demonstrate the ability of the system to sustain shifting with high intermittency cloud cover. Note the rapid and sustained drop in PV output due to a strong thunderstorm passing through. The shifting battery was able to respond and sustain a firm output.

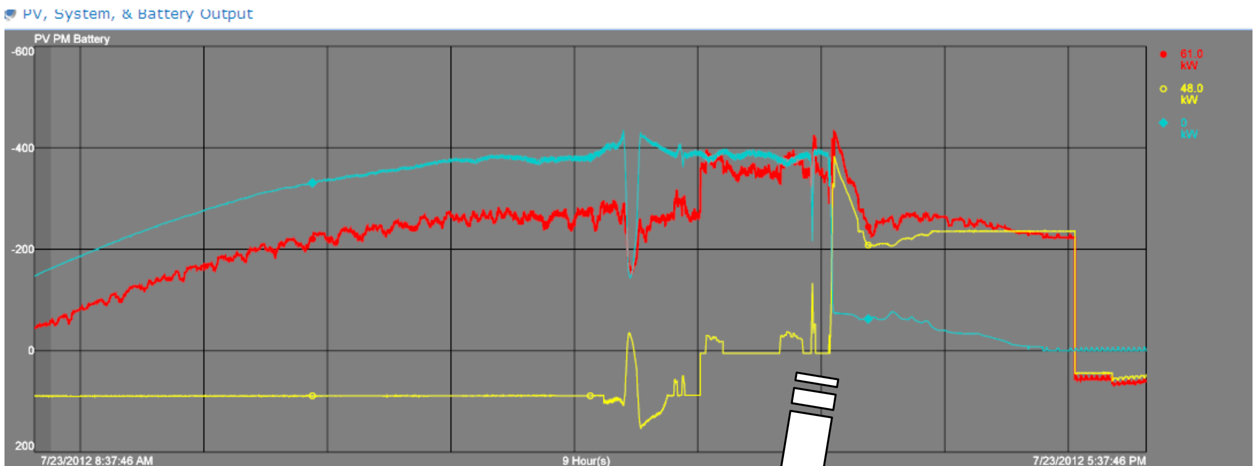

Figure 38 - Shifting with Cloud Intermittency

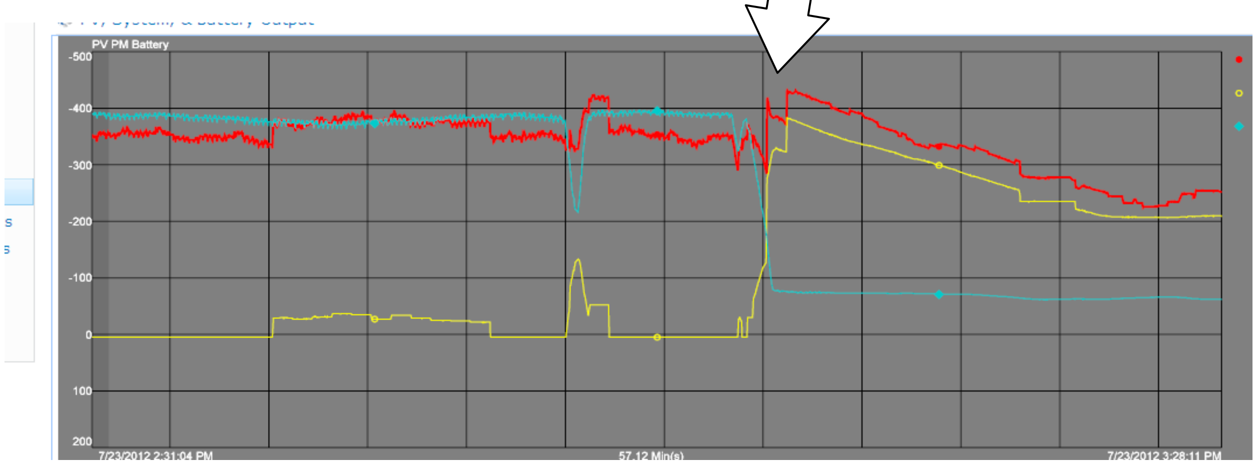

Figure 39 - Magnified View of Shifting with Cloud Intermittency

4.2.1 Key Observations Shifting

- The shifting algorithm works very well and is quite accurate on clear days. There is lowered confidence in the output on cloudy days.
- SoC limits and rate of charge both limit the amount of morning PV that can be stored, especially in the summer schedule.
- The automation was hindered by software versioning issues.
- Other shapes for firmed output need to be investigated. WSM doesn't care too much for the sharp drop off in the evening (summer schedule)

4.3 Simultaneous Smoothing and Shifting Field Results

The ability to create a firmed product through shifting during cloudy days remains a challenge but the output is roughly approximating a firmed shape. As Figure 40 shows, PV intermittency does have an effect on the firmed shape output, in this case the effect appears minimal as the cloud induce intermittency was not large.   Note also that the periodic spikes in battery charging (downward pulses) were due to an unforeseen drift in SoC on the shifting batteries. Incorporating a dead band in the algorithm removed these charge pulses.

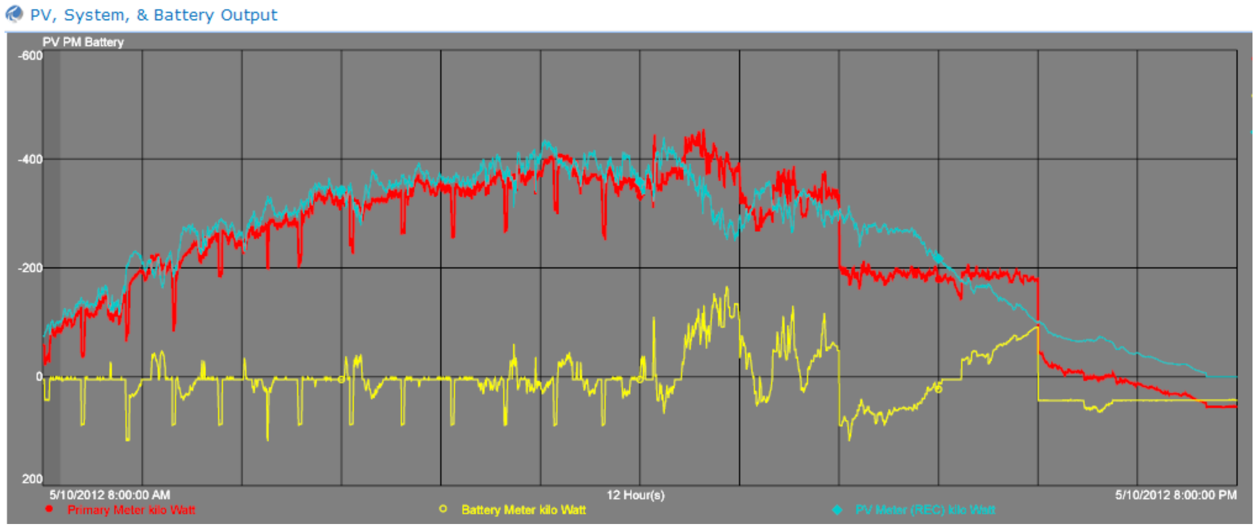

Figure 40 - Simultaneous Smoothing and Shifting - Low % Cloud Cover

In Figure 41 - Same Day Smoothing and Shifting the smoothing takes place in the morning, the clouds clear in the afternoon and shifting takes place. Note the smoothing battery operating simultaneously with the shifting performing a morning charge of the PV.

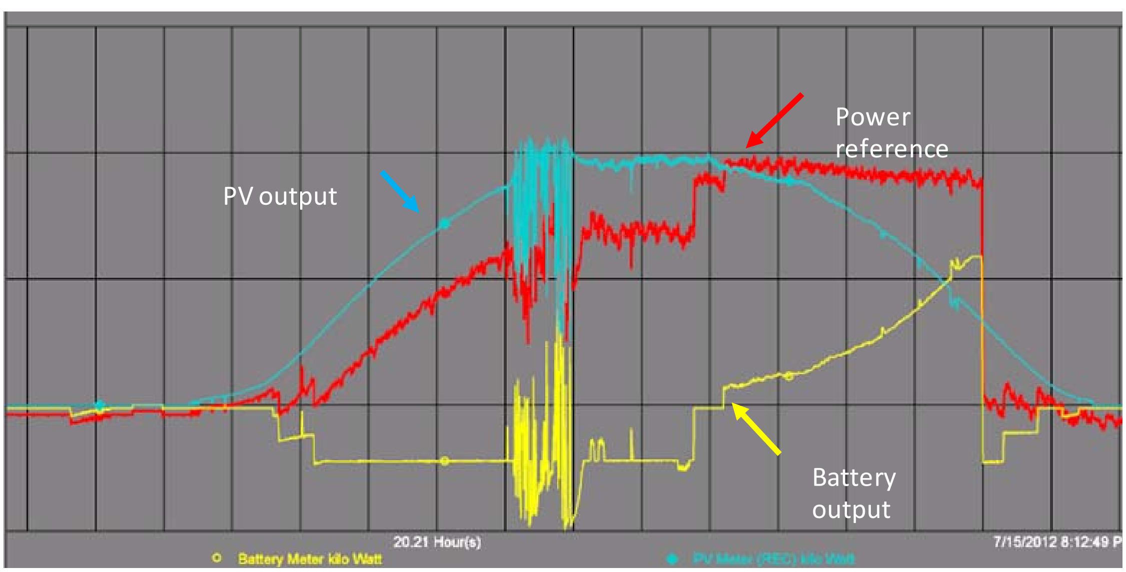

Figure 41 - Same Day Smoothing and Shifting

Simultaneous smoothing and shifting discharge takes place in Figure 42. During days with heavy intermittence the system was able to charge the shifting, simultaneously store shifting power and in the afternoon produce a firmed PV product, albeit with a lowered confidence in the kW delivered on a firm basis.

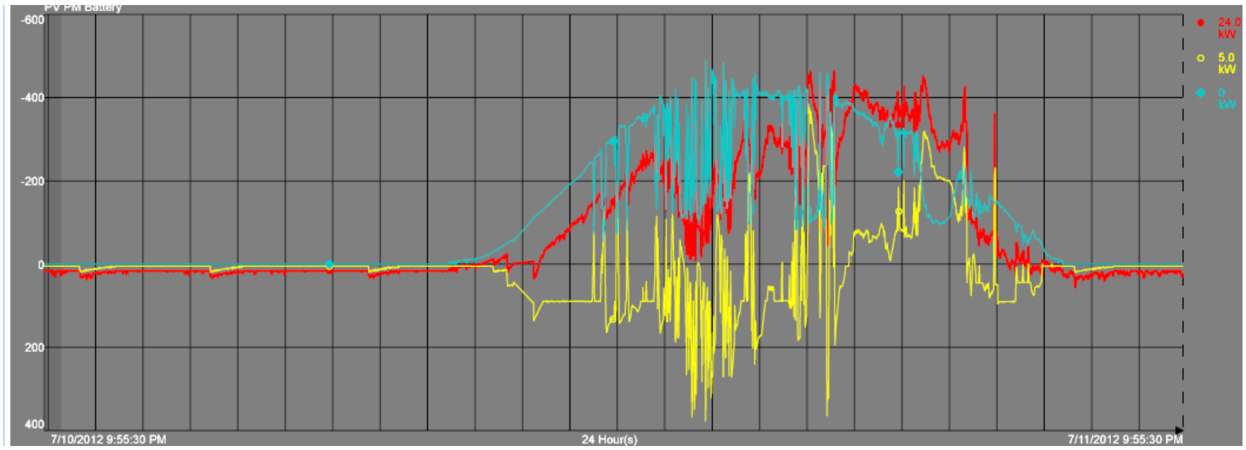

Figure 42 - Simultaneous Smoothing and Shifting - High % Cloud

4.3.1 Key Observations - Simultaneous Smoothing and Shifting

- Simultaneous Shifting and Smoothing with lots of intermittent PV is achievable but the shifting power reference may need to be lowered during cloudy periods to ensure the firmed output remains flat without spikes especially during instances where the smoothing battery performs a quick and deep charge.

4.4 Validation of the Feeder Model

Without a detailed and accurate model of the connected feeder, the benefit of recording data will not be realized. Any comprehensive analysis requires a dependable and accurate model to be coupled with and used as a tool for further investigations and studies.

Feeder models were matched with the recorded demand at the substation. Individual load models were not modeled for the first phase of the project because the main concern was matching the cumulative load seen at the feeder source instead of developing matched model for individual loads. Figure 43 shows an arbitrary load shape developed based on the feeder's load shape. A random load connected to that feeder is assumed to have such a load shape.

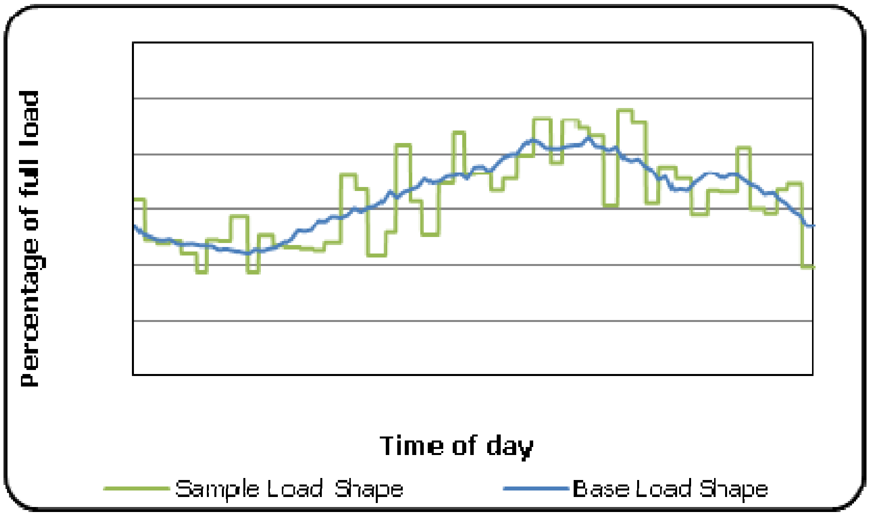

Figure 43- Sample and base load shapes

Figure 44 shows the calculated load at the feeder source, matching the recorded load for the same period of time.

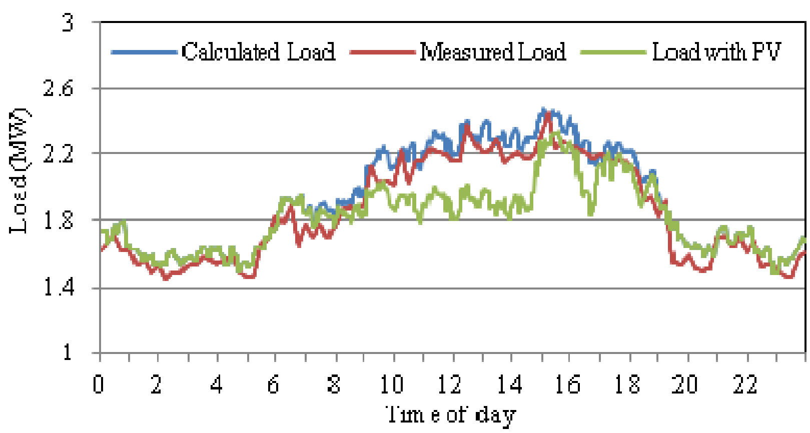

Figure 44 - Measured and Calculated load at the substation

With prepared feeder models, sophisticated analysis and simulations were then performed. Preliminary analyses were performed to study the voltage profile at various nodes of the feeder including high penetration of PV as well as the effects on the power quality.

Once the loads were added to the model, the results had to be validated and compared to the observed demand at the substation. As shown in Figure 45 and Figure 46, cumulative load at the substation with 1-minute LRT has sharper variations than the observed demand data while it follows the same trend feeder demand shows. It was necessary to calibrate load shapes to get the best cumulative load at the feeder's source.

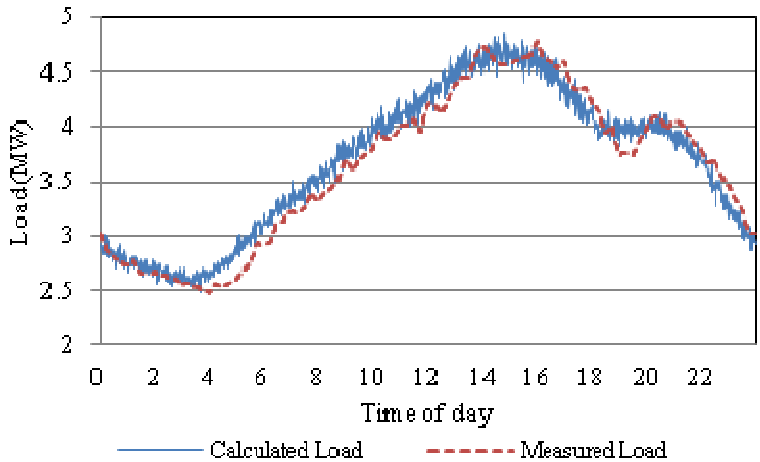

Figure 45 - Measured and Calculated load at the substation (Sep. 2, 2010)

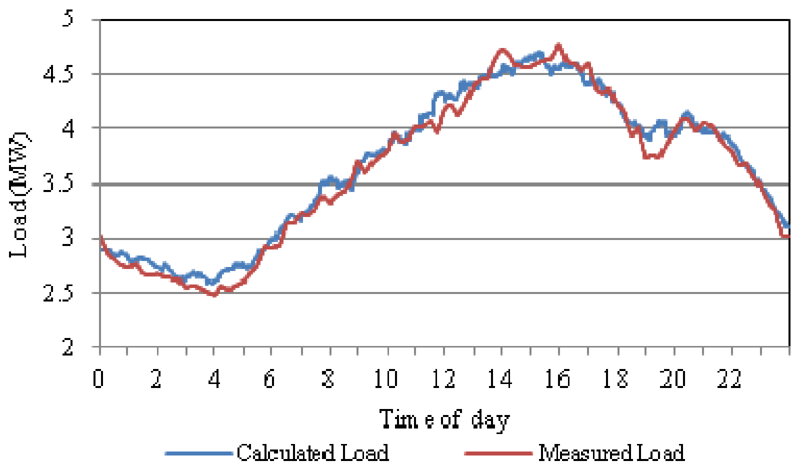

Figure 46 - Measured and Calculated load at the substation (LRT: 30 min, Sep. 2, 2010)

To show whether or not the proposed method is sensitive to changes in feeder's loading level, simulation period, seasonal load composition and feeder itself, several case studies were conducted for different seasons and demand levels on other feeders. It was assumed that the feeder's topology had no change in the course of study. Results show adequate consistency with quite similar error levels. Similar random load allocations were performed for different time periods. Samples of the results for some of the simulations are presented in Figure 47 - Measured and Calculated load at the substation (LRT: 30 min, Nov. 1, 2010)
Levels show minimal variations and comply with the results from earlier load allocations.

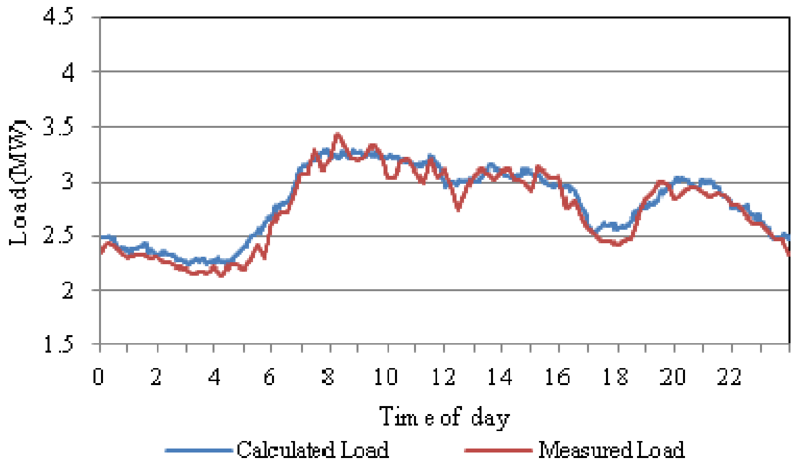

Figure 47 - Measured and Calculated load at the substation (LRT: 30 min, Nov. 1, 2010)

Yet to be analyzed are several proposed test plans which will be simulated in advance on the test bed (feeder models) and prioritized based on the simulation results.

4.5 Validation of the Smoothing Model

The goal of smoothing effort is to counteract the power intermittency from PV by controlled discharging of the energy from the fast UltraBattery™. The project is evaluating different PV variables including PV output power and PV irradiance with the latter a leading indicator of PV output power. Figure 48 illustrates simulated fast charging and discharging of the smoothing battery sufficient to meet the Smoothing Control Strategy for the given feeder load.

Another important concern with the control of BESS is the charge/discharge rates (or “ramp” rates), which are limited so as to lessen the Whr throughput of the BESS for better longevity. Figure 48 shows ramp rates for the battery and Figure 49 for simulation results. Ramp rates less than 100kW/s are sufficient for the simulation consistent with Smoothing Control Strategy for our system.

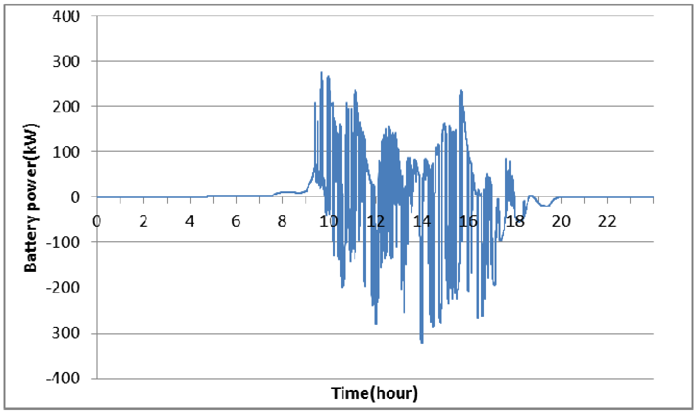

Figure 48 - Ultrabattery power levels during fast charging and discharging to counteract PV intermittency

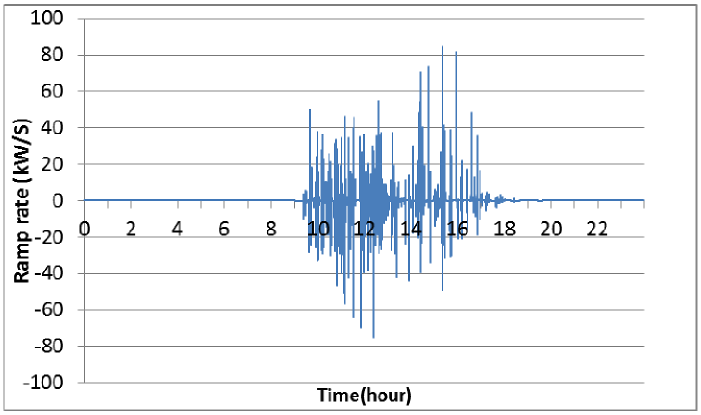

Figure 49 - Ramp rate variations during smoothing operation of the battery

4.5.1 Comparison of Smoothing Algorithms

Three smoothing algorithms,: moving average, dual moving average and moving median were analyzed. In order to make the output smoother, the moving average algorithm can be used twice, however the subset is half of size which is used for moving average algorithm. In one example the moving average algorithm uses the 600 seconds as the size of subset, the dual moving average algorithm then uses the moving average algorithm twice over the 300 seconds subset. These two algorithms can have the same lag. The result will be smoother than that from using moving average algorithm once. From Figure 50, we can see the result from dual moving average algorithm is smoother than moving average algorithm.

Statistically, the moving median can track the trend of the PV outputs better than moving average since it mitigates rapid transitions. The moving median tracks the median for a time series of results. It ignores the rapid changes and is more suited to the cloud induced variations.

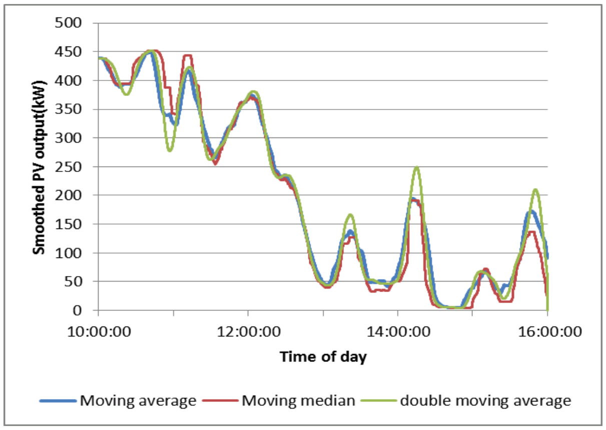

Figure 50- Comparison of Smoothing Results – Output

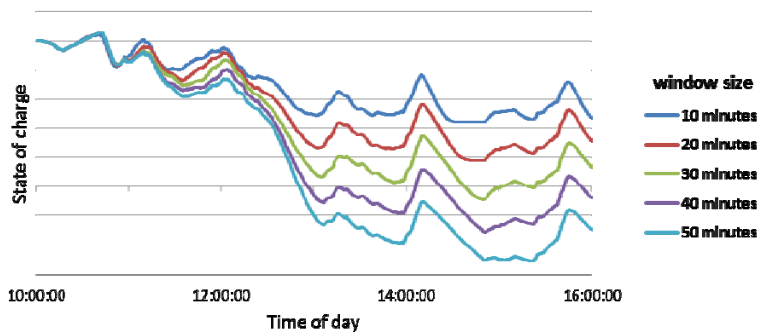

Figure 51 - Comparison of Smoothing Algorithms – SoC

For the moving average and moving median algorithms, the charging, discharging and ramping rate are in same range. The two differences among these three algorithms are smoothness and SoC. The dual moving average algorithm can get the smoothest result since it uses the average algorithm twice. The moving median algorithm is most robust since it ignores the rapid changes.

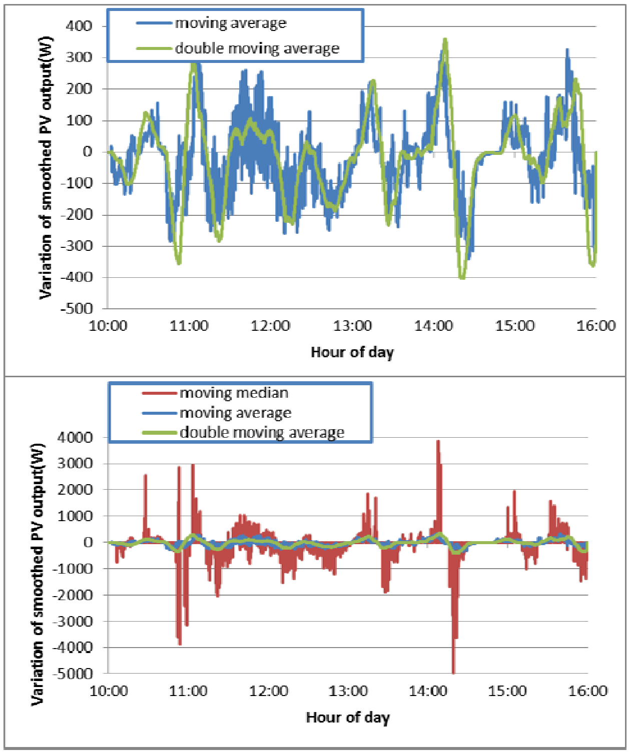

Figure 52- Variation of Smoothed PV Output

The variation of two consecutive points in smoothed output were used to measure the smoothness. From Figure 52, the dual smoothing average algorithm shows the lowest variation. Considering it has same SoC with other two algorithms, it appears to be the most suitable algorithm amongst the three tested.

4.6 Smoothing Simulation Results

The smoothing algorithm was tested and tuned on actual PV data prior to implementation at the Prosperity Site. Table 5 below shows the default algorithm parameters noting that AUX1 and AUX2 were not used (these will be used in future efforts to drive in external control signals such as ACE).

Symbol	Name	Units	Default Value
T_W	PV Moving Average Time Window	seconds	3600 (1 hour)
T_1	PV Low Pass Filter Time Constant	seconds	3600 (1 hour)
T_2	AUX1 (load) Low Pass Filter Time Constant	seconds	3600 (1 hour)
T_3	AUX2 (ACE) Low Pass Filter Time Constant	seconds	0
Flag	Switch between LPF and MA	0 or 1, 0=use MA, 1=use LPF	1 (use LPF)
G_1	PV Smoothing Error Gain	unitless	1 (for 100% compensation)
G_2	AUX1 (load) Scaling Factor	unitless	depends on magnitude of AUX1 signal
G_3	AUX2 (ACE) Scaling Factor	unitless	Depends on magnitude of AUX2 signal
G_4	SOC Tracking Gain	unitless	1000
DB	Dead Band Width	kW	+/- 50
SOC_{REF}	Reference State of Charge	unitless (within defined SOC limits)	0.6

Table 5 – Default SNL Smoothing Algorithm Parameters

Test cases examine tradeoff between choices of gains G1 and G4 as well as dead band widths and use of low pass filter vs. moving average for smoothing profile

4.6.1 Smoothing Simulation Test Case #1

This case used values of G1 = 1, G4 = 1000. The results illustrate a balance between smoothing error and battery effort. Figure 53 shows, from top to bottom, plots of PV output, desired smoothing profile, PV + Battery power, smoothing error, and actual Battery power added.

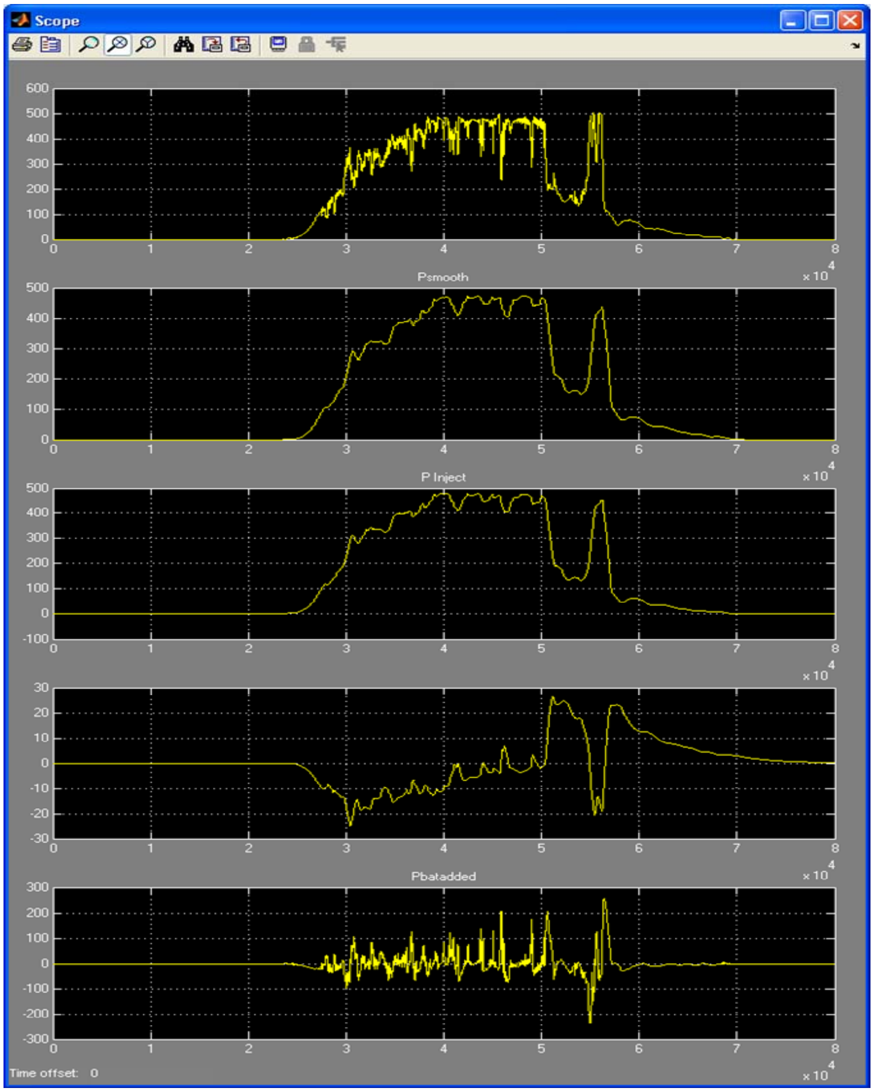

Figure 53 _ SNL Test Case #1 Results

4.6.2 Smoothing Simulation Test Case #2

This case used values of G1 = 1, G4 = 1000. The results in Figure 54 illustrate less Smoothing Error but More Battery Effort.

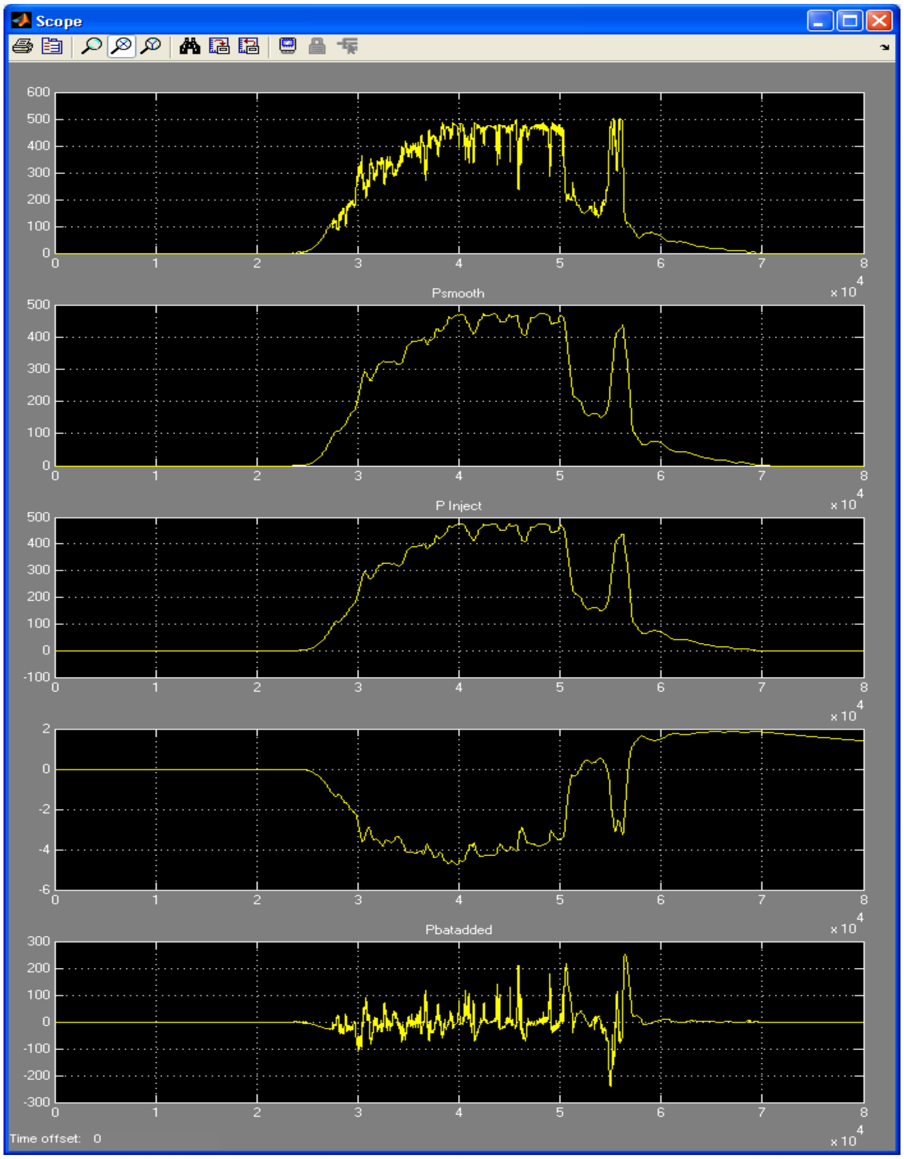

Figure 54 - SNL Test Case #2 Results

4.6.3 Smoothing Simulation Test Case #3

This case used values of G1 = 1, G4 = 100. The results in Figure 54 illustrate more smoothing error but less battery effort.

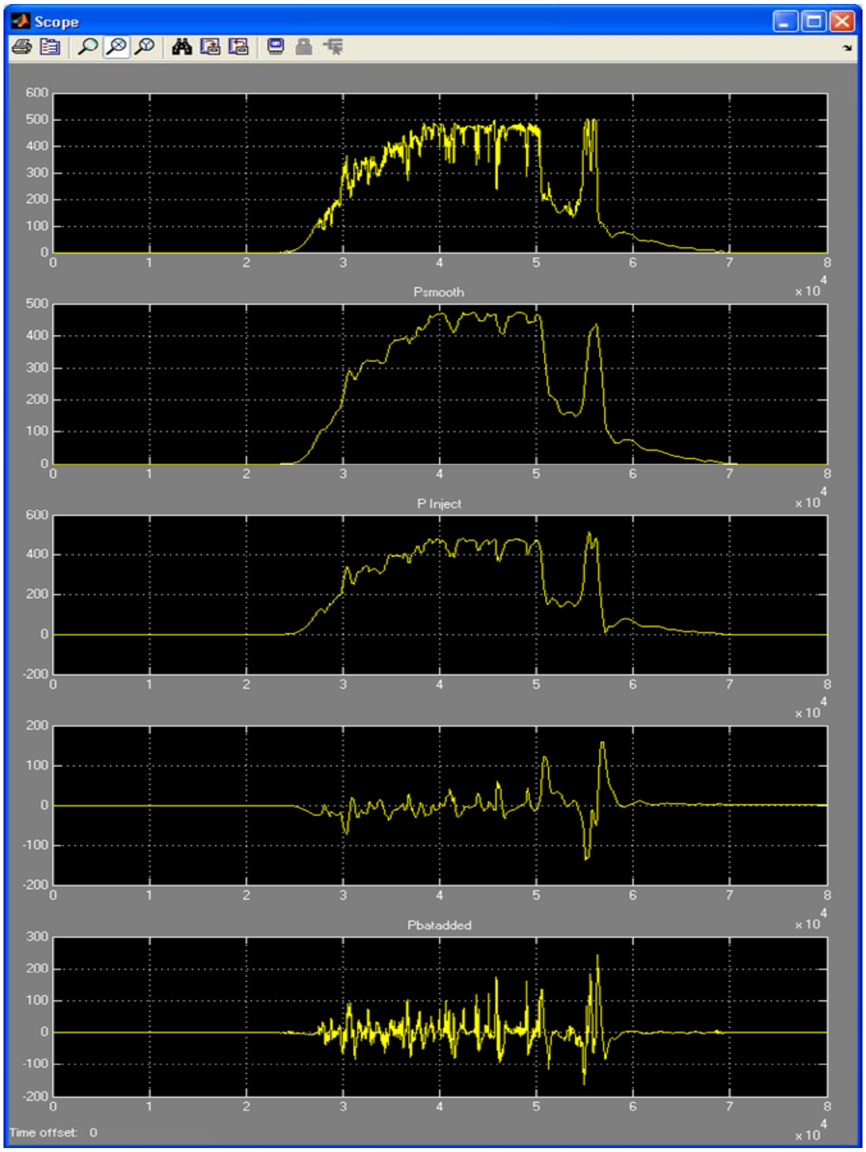

Figure 55 - SNL Test Case #3 Results

4.7 Validation of Shifting Model

From Figure 56 below, it is apparent that the PV forecast is very close to the real PV output for a clear day when we consider the influence of temperature over the PV output. The temperature factor we use is -0.3%/K, which means the PV output will decrease by 0.3% for the increase of one kelvin.

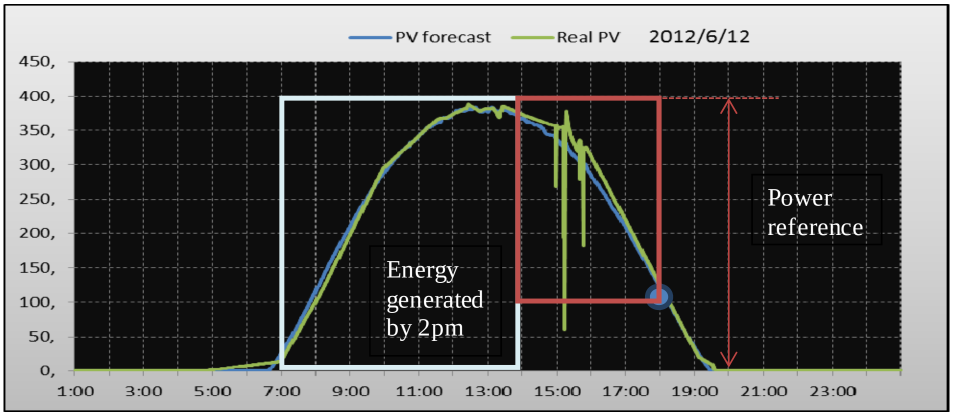

Figure 56 Comparison between Real PV out and Forecasted PV Output

The power reference during the summer peak load time (2pm to 6pm) is decided by three factors: the energy generated by PV before 2pm, the energy generated by PV during peak load time, and the minimum PV power output during peak load time. We will evenly dispatch the stored energy before 2pm from battery into the peak load time. Even for a cloudy day the battery can get fully charged before 2pm. The PV output forecast during peak load time is more important in the calculation. First, we add the energy that could be provided by battery during peak load time and energy generated by PV during peak load time together. Secondly, we divide the sum by 4(4 hours). The result is the power reference based on energy. Since the maximum battery output is 250kW, the power reference should not be greater than the sum of minimum PV output and 250kW. The minimum PV output happens at 6pm. So we need adjust the calculated power reference to be equal or less than the sum of PV output at 6pm and 250kW. Figure 57 show real world output where the power reference is held stable while the afternoon PV production declines.

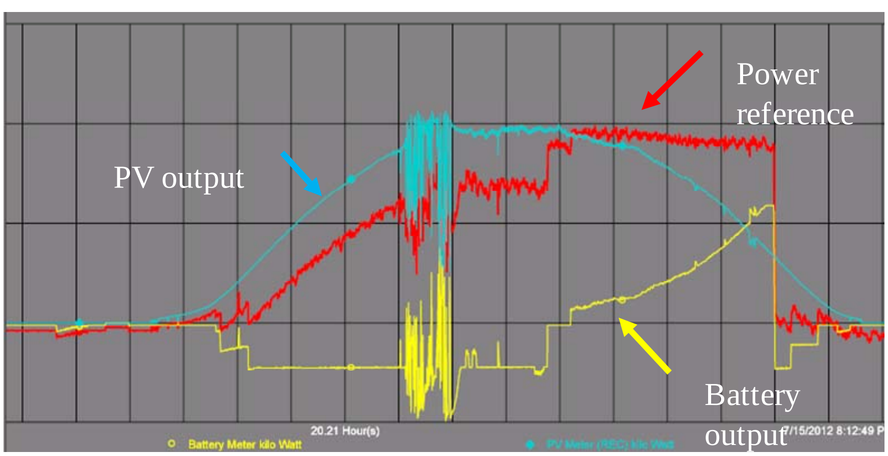

Figure 57 – Actual Shifting Results from Field

In Table 6, a comparison of actual vs modeled results, the real PV output at 6pm is 128kW, and the PV output forecast is 124kW. The power reference is calculated as 373kW based on energy. Considering the difference between 373kW and 124kW is less than 250kW, the power reference-373kW, needn't be adjusted. The true power reference is 378kW. Only 5kW difference occurs for these two values. Hence the weather forecast works well for shifting in a clear day. Future work will explore forecasting results for varying weather condition.

	Real data	Forecast
PV output at 6pm	128	124
Power reference	384	373
Adjusted power reference	378	373

Table 6 – Shifting Model vs Real Data Results

Further analysis confirms a stable and accurate model as represented in Figure 58, Figure 59 and Figure 60.

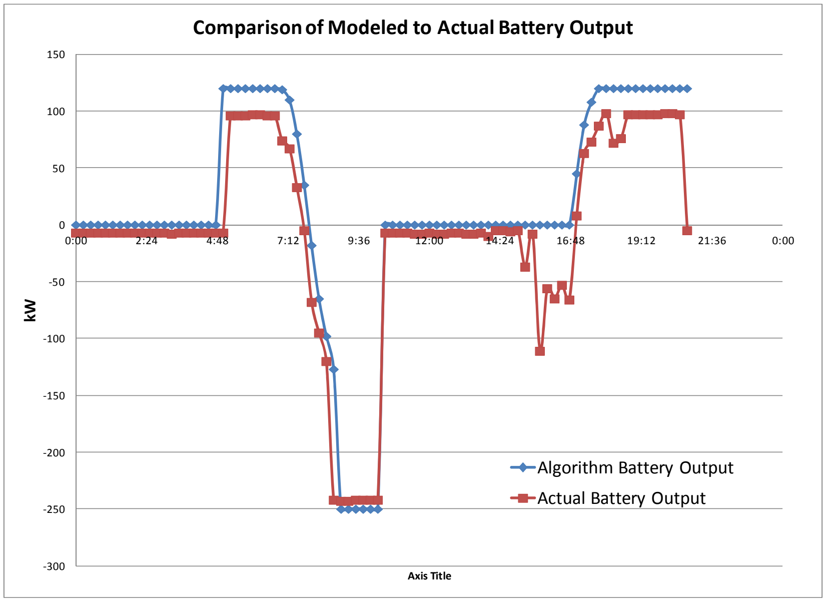

Figure 58 - Shifting - Model Comparison of Battery Output

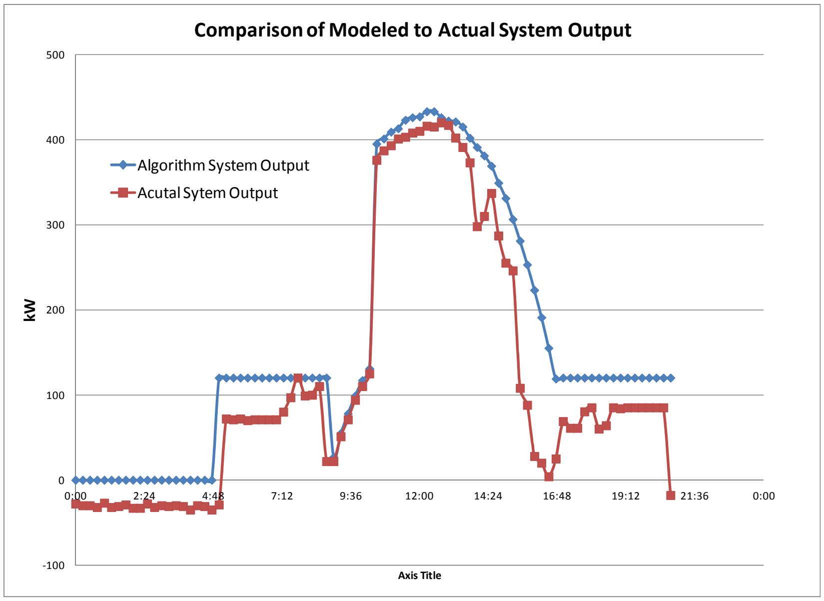

Figure 59 - Shifting - Model Comparison of Primary Meter Output

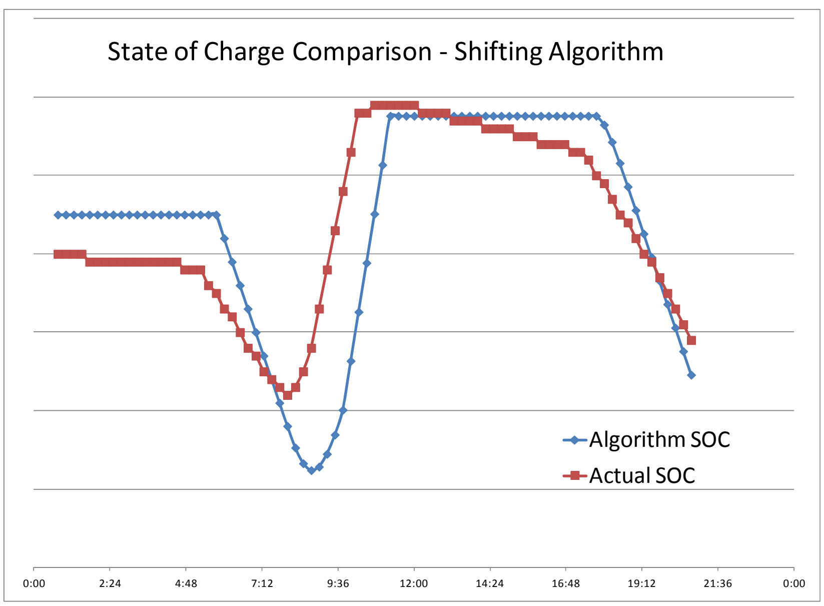

Figure 60 - Shifting - Model Comparison of SoC

4.8 Ramp Rate Methodology Comparison Results

As the graphs in Figure 61 and Figure 62 indicate there is significant smoothing being implemented. The plot of the empirical probability distribution for the Primary Meter lies well above the PV Meter's ECDF. We note that the Primary Meter signal was contaminated by an extra signal from an HVAC load in summer months when the air conditioners are operating. To compensate for this we introduced an additional level of smoothing when calculating the ramp rates for the Primary Meter. This will be corrected in succeeding test plans.

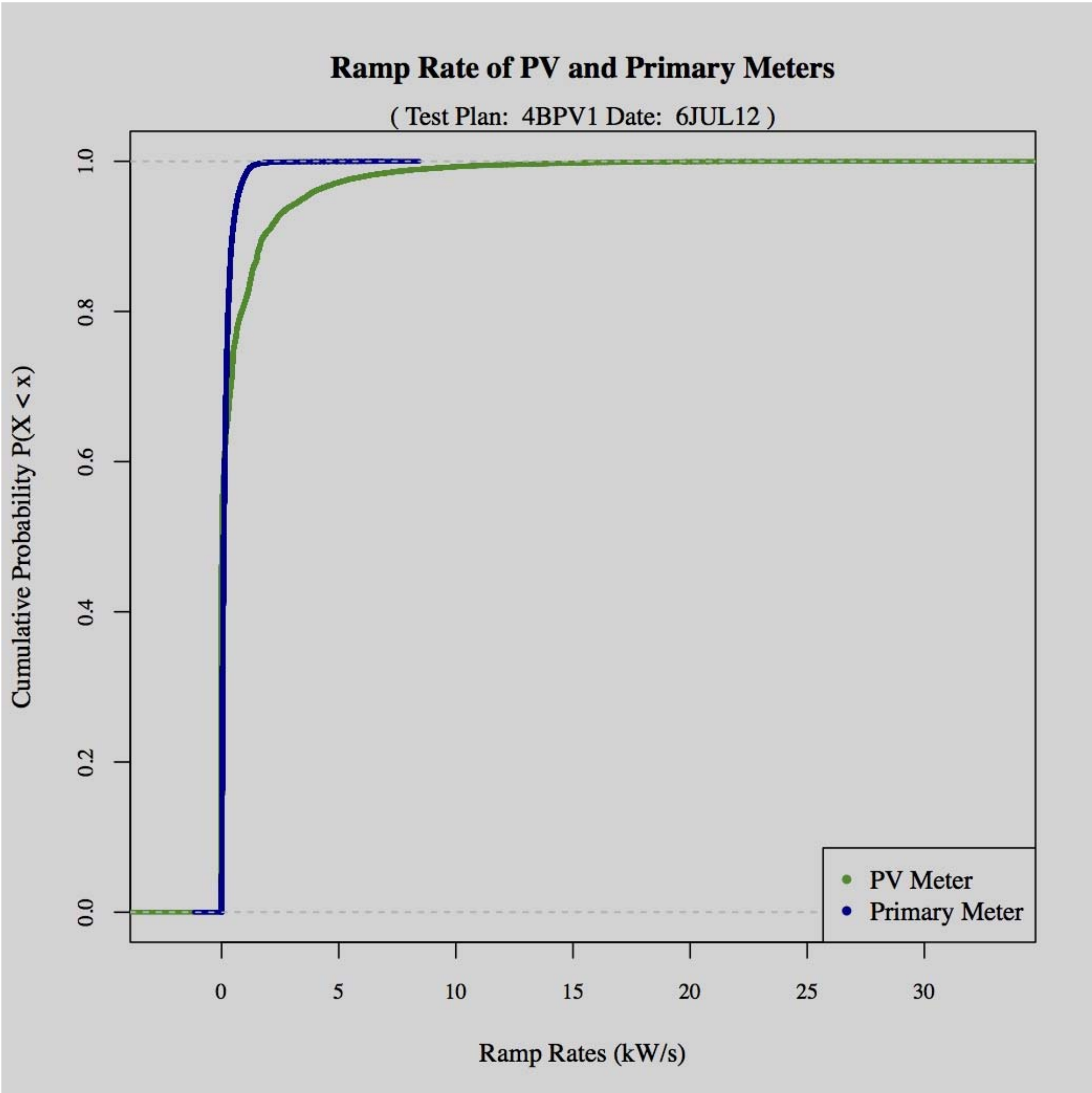

Figure 61 – Primary Meter and PV Meter ECDF – July 6, 2012

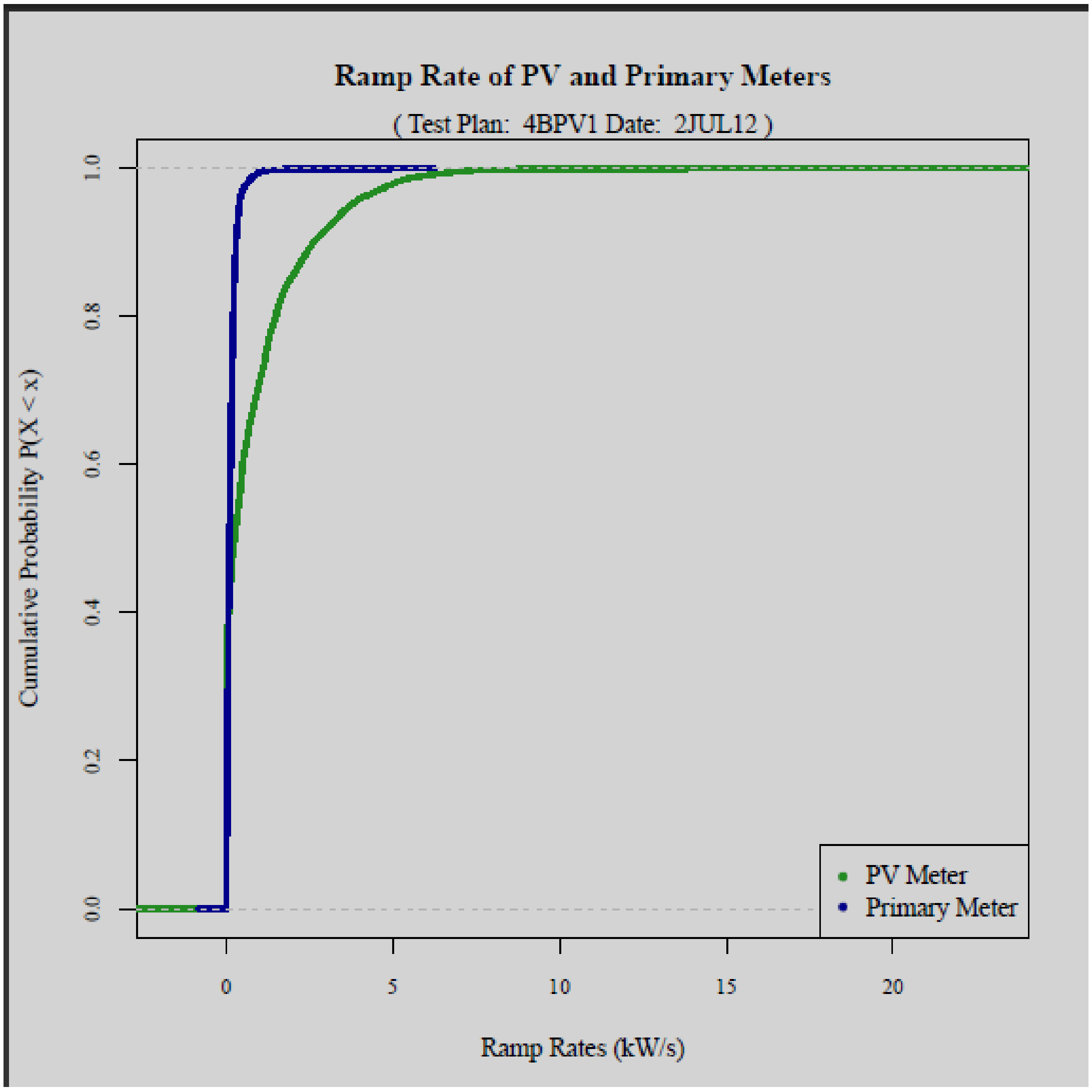

Figure 62 - Primary Meter and PV Meter ECDF – July 2, 2012

4.8.1 Technical Aspects

The measurement for the degree of smoothing is

$$A = \frac{\int_0^\infty (1 - ECDF_{PM})dr}{\int_0^\infty (1 - ECDF_{PV})dr}, \qquad \text{Equation 7}$$

where the empirical cumulative distribution functions are $ECDF_{PV}$ for the ramp rates observed with the PV meter measurements and $ECDF_{PM}$ for the ramp rates observed with the Primary Meter measurements. With *A* as the dependent variable the following are the independent variables considered:

- Smoothing control source (a categorical independent variable)

- o Cloud cover (an ordinal or a ratio independent variable)
- o Increment of battery capacity (an ordinal or a ratio independent variable)
- o Potentially season (an categorical variable)

Smoothing splines are among the best options for calculating derivatives, typically giving performance well above any finite-differencing method. For doing off-line analysis there is little reason to utilize any other method. For online processing of data splines may not be ideal. They are a global method, so any point of evaluation relies, at least indirectly, on a whole day's measurements. Online processing would be ideally handled using Savitzky-Golay filters. These are a finite-length, fixed-coefficient filter provided there is even sampling times. The Savitzky-Golay filters act simultaneously as a low-pass filter and a differentiator. Difficulties arise when sampling times are not evenly spaced. Now the coefficients are no longer fixed and must be calculated 'on the fly'. It's unlikely that this would prevent their use numerically, since the actual calculations could be performed relatively quickly. But, this is still an unsolved problem, so an actual algorithm will need to be designed prior to any implementation.

It needs to be emphasized that this project is the first to use smoothing splines and Savitzky-Golay filters for ramp rate calculations. These methods are mathematically among the best for calculating derivatives. This methodology is on theoretically solid ground by employing these techniques, not relying on any prior ad-hoc methods. [3]

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[3] Ahnert , Karsten , Abel , Markus, Numerical differentiation of experimental data: local versus global methods, Computer Physics Communications, V177, N10,p 764-774, 2007

Hanke , Martin, Scherzer , Otmar, Inverse Problems Light: Numerical Differentiation, The American Mathematical Monthly, V108, N6, 2001

Jianwen Luo, Kui Ying, Ping He, Jing Bai, Properties of {S}avitzky–{G}olay digital differentiators, Digital Signal Processing Journal, V15, P122-136, 2005

Reinsch, C., Smoothing by spline functions, Numerische Mathematik , V10, N3, p177-183, 1967

Reinsch, C., Smoothing by spline functions, Numerische Mathematik , V16, N4, p451-454, 1970

Ronald W. Schafer , What Is a {S}avitzky-{G}olay Filter?, IEEE Signal Processing Magazine, V2, N4, p111-117, 2011,

4.9 Ramp Rate Analysis Results

4.9.1 Historical Irradiance Data

Irradiance data which was recorded at a sample rate of 0.2 seconds was selected, intentionally seeking cloudy days which exhibited significant variability. Below, Figure 63 shows the irradiance data for April 10th, 2012 through April 12th, 2012.

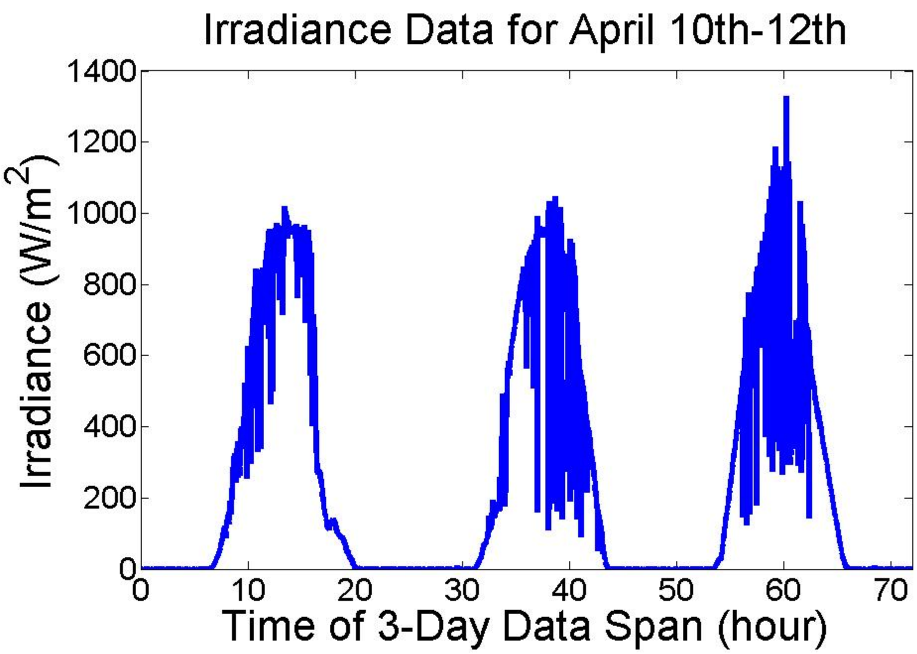


Figure 63 - Irradiance Data for April 10th through 12th, 2012

Because of the greater accuracy of the fourth-order central difference method, it was used for obtaining the final results using actual irradiance data keeping in mind that smaller time step ramp rate calculation may produce inaccurately high ramp rates. This regular time step of 0.2 seconds was used in preliminary testing of the code. However, the time stamp for the irradiance data ranged from about 0.2 to 0.7 seconds (at a precision of +/- 0.001 seconds) during a day's data collection. Accuracy was increased greatly by incorporating the difference in time stamps belonging to data points used to calculate ramp rates. Figure 64 shows the ramp rates calculated throughout the day along the same timeline as the irradiance data shown above in Figure 63.

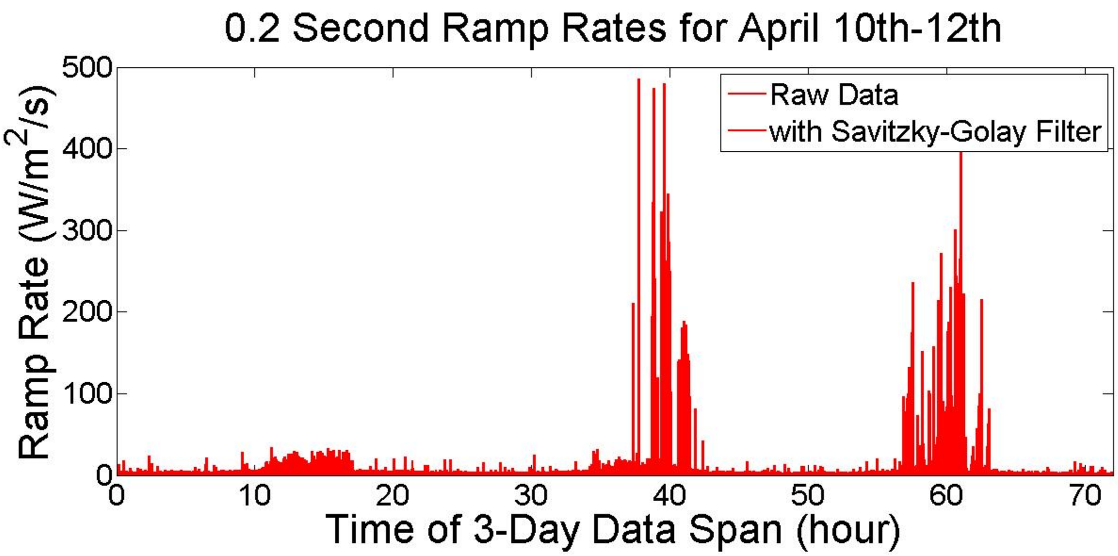


Figure 64 - Ramp Rates Using Time Stamp Difference (0.2 second Sample Rate)

A primary concern of ramp rates is the maximum ramp rate the battery bank providing output power for smoothing may experience. Below, Figure 65 shows the variation of maximum ramp rate depending on sampling rate for each of the three days.

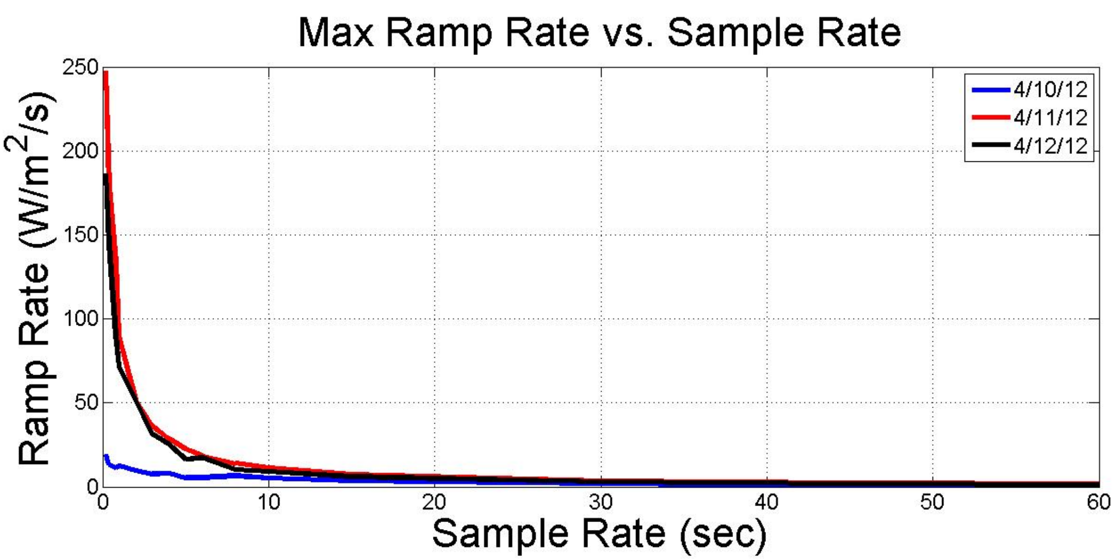


Figure 65 - Max Ramp Rate versus Sample Rate

The same data shown on a logarithmic scale for both the x and y axes is shown below in Figure 66. Both of these graphs show a clear increase in maximum ramp rate as sampling frequency increases.

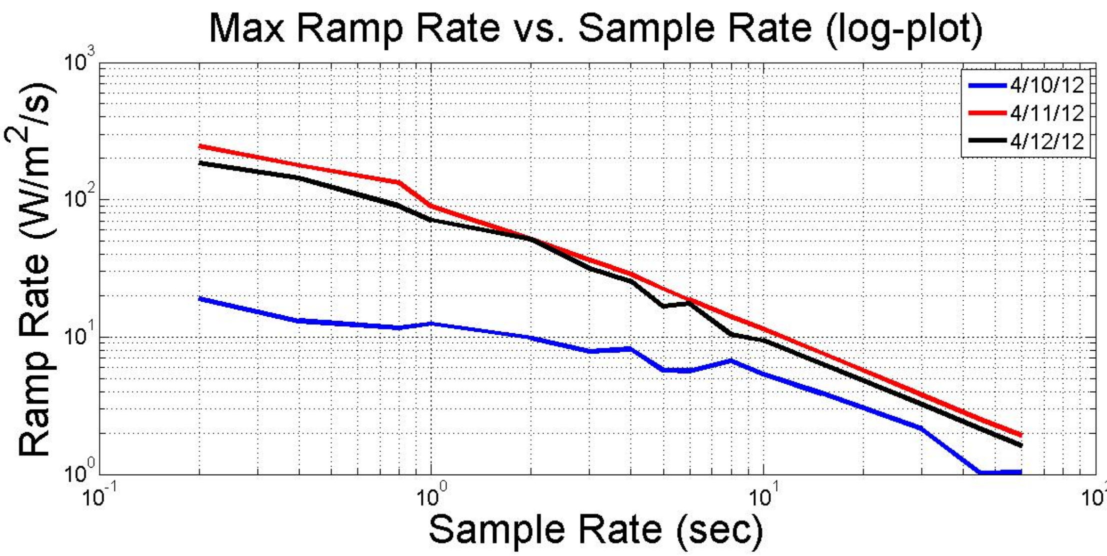


Figure 66 - Max Ramp Rate versus Sample Rate Log-Plot

Additionally, the average ramp rate for each day was calculated to see its trend using Equation 8 (Average Ramp Rate) for ramp rates calculated using the forward difference method.

$$Avg.Ramp\ Rate = \left|\frac{\sum_{i=0}^{X-1} f(x_i) - \sum_{i=0}^{X-1} f(x_i + h)}{Xh}\right| \qquad \text{Equation 8}$$

In Figure 67 below, the sliding average ramp rate distribution progression using Equation 8 for April 10th is shown versus the sample rate used for equation 3 with sample rates of 10 seconds, 5 seconds, 2 seconds, 1 second, and 0.2 seconds. Again, it is shown that the calculated ramp rate distribution spreads out with decreasing time interval, but unlike other distribution series, the progression is much smoother.

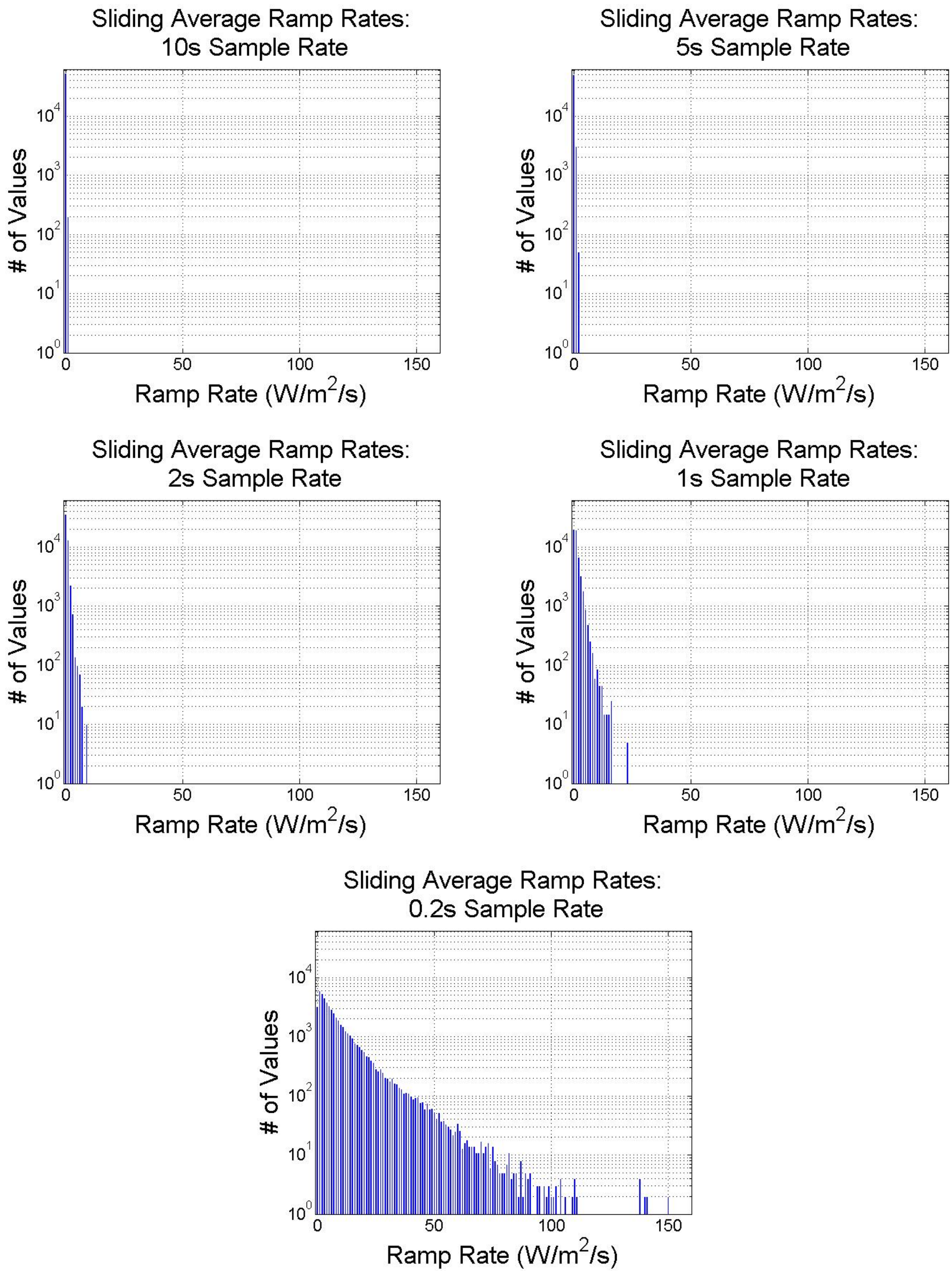
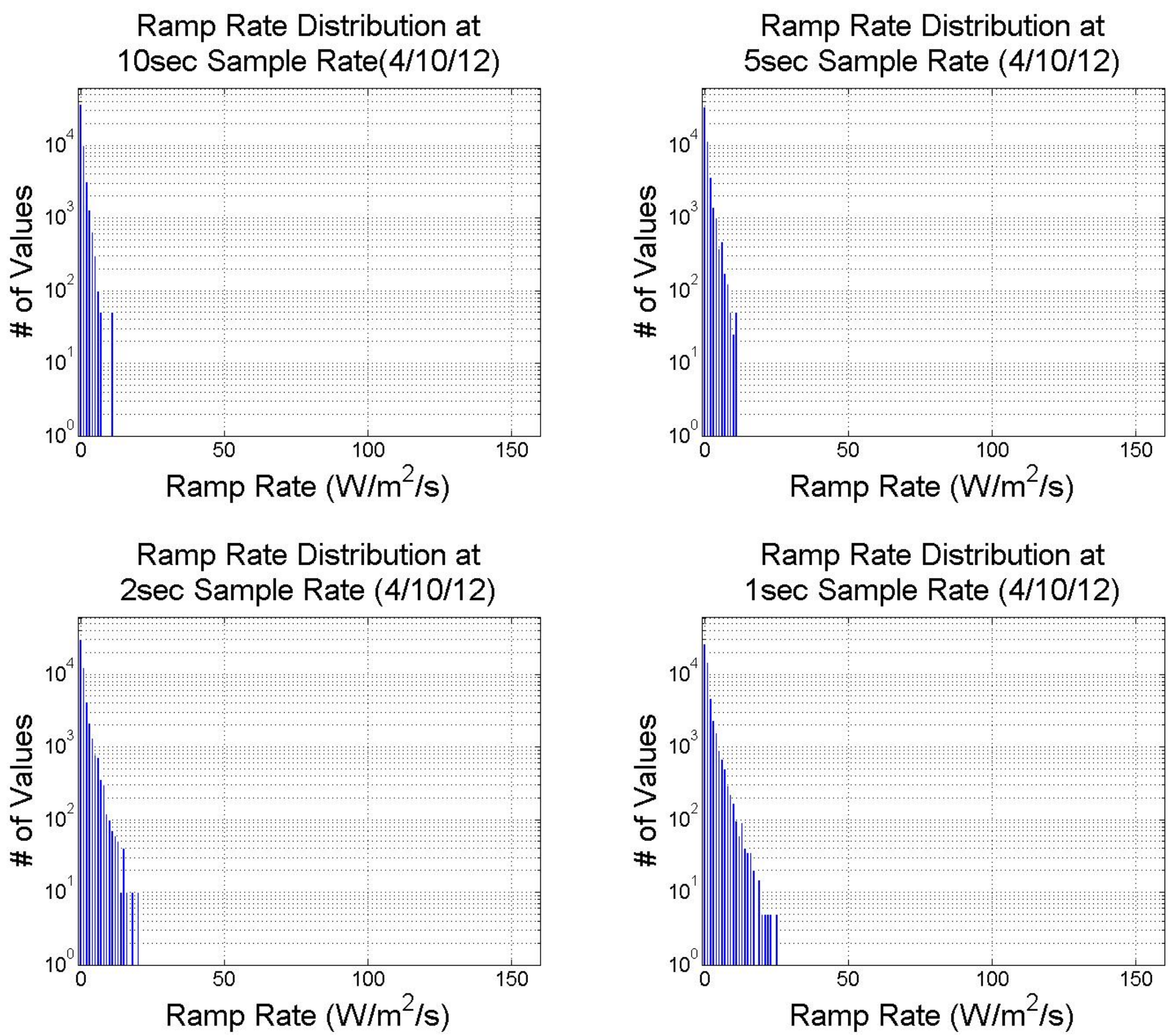


Figure 67 - Sliding Average Ramp Rate Distribution

Additionally, the maximum ramp rate for sliding average data above is significantly higher as compared to the distribution progression shown below in Figure 68. This may not be a desired outcome because artificially high ramp rates may be generated.



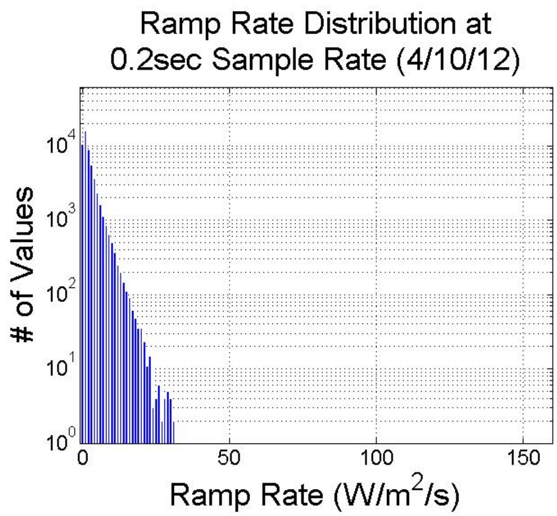
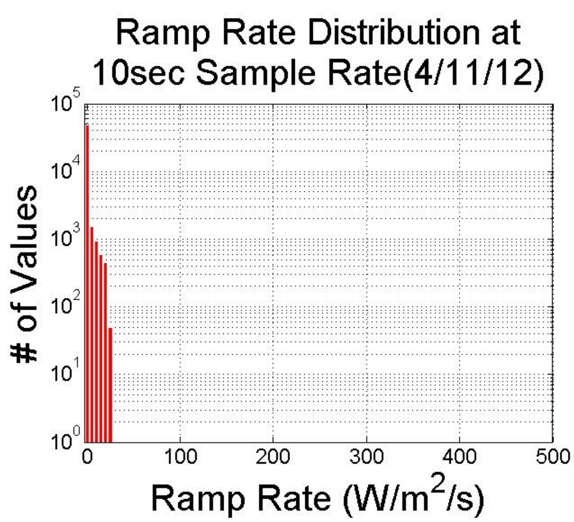
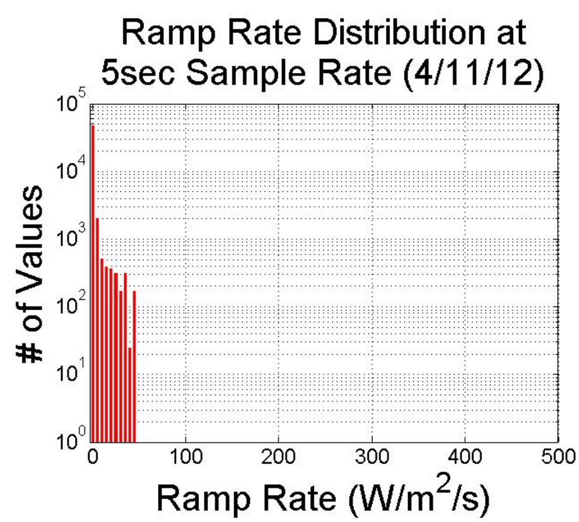


Figure 68 - Ramp Rate Distribution for April 10th, 2012

Taking a closer look at the highest variability day, April 11th, we can see each distribution as it changes due to varying sampling rate in the plots in Figure 69. Being on the same window size, one can see the distribution spreading out to higher ramp rate values as sample rate decreases to 0.2 seconds from 10 seconds. Comparing the distribution progressions for the same day using either the backward difference or 4th order difference method, in Figure 70, the peak or maximum ramp rate varied from 300 to near 350 W/m^2/s.





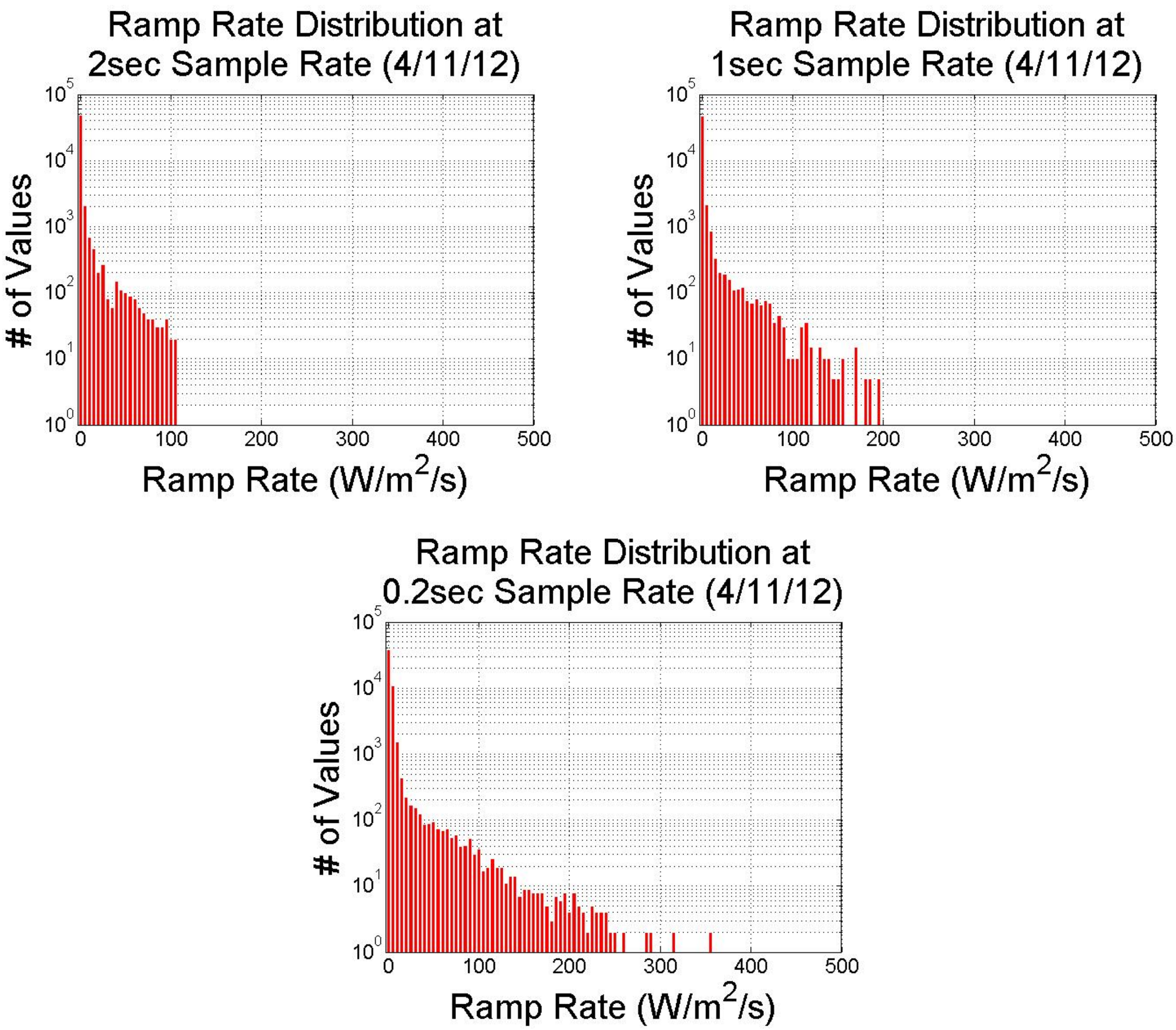


Figure 69 - Backward Difference Distribution at each second sample rate for April 11th, 2012

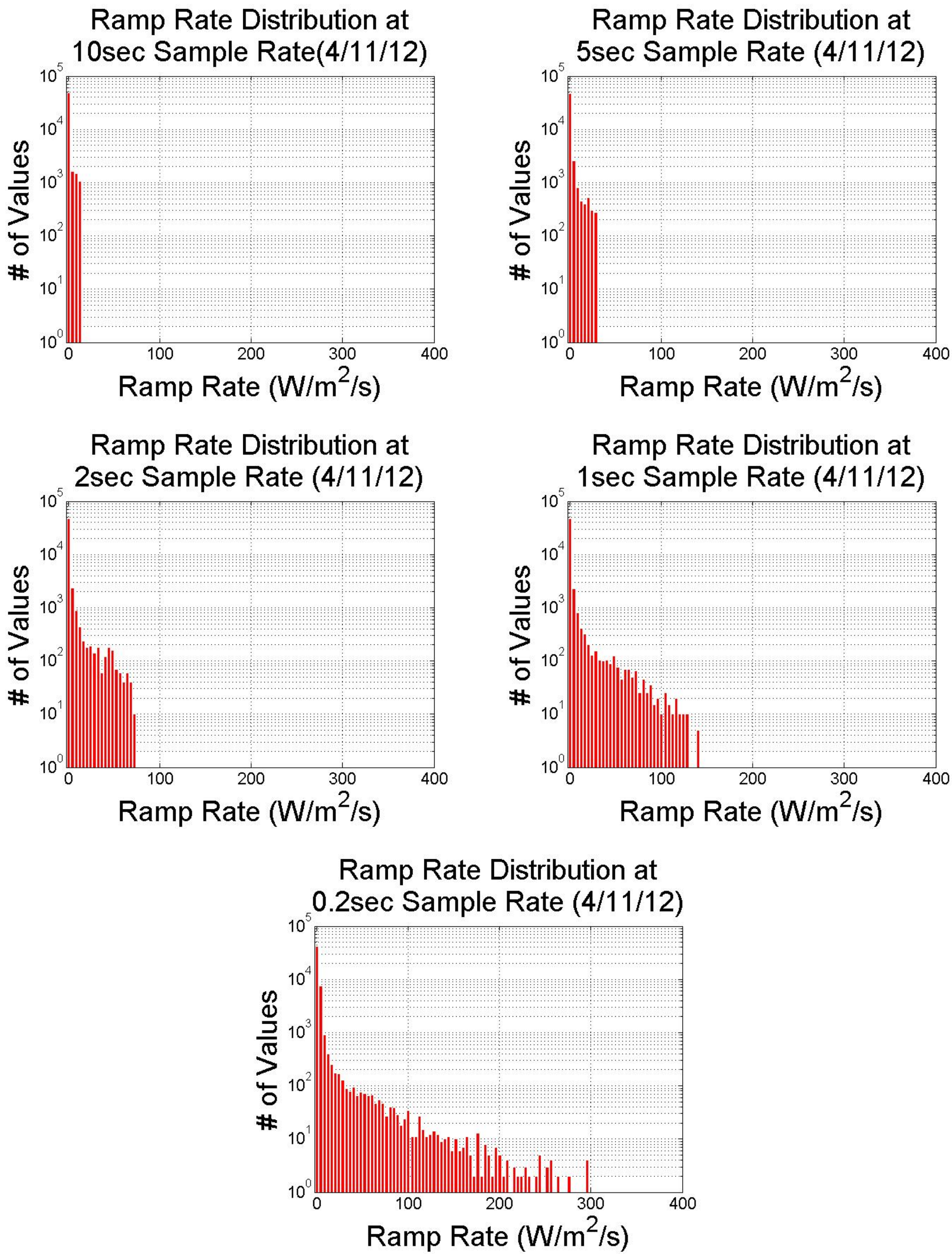
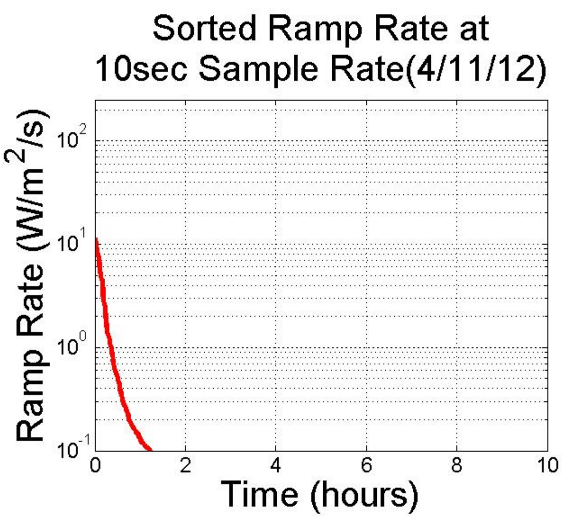
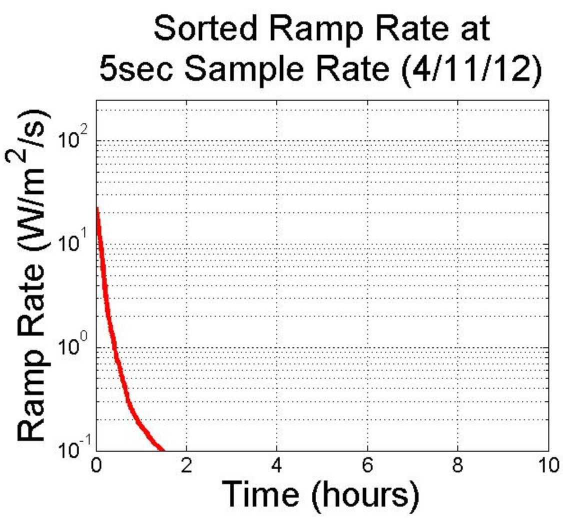


Figure 70 - 4th Order Distribution at each second sample rate for April 11th, 2012

The irradiance data available provided a smallest average sample rate of 0.2 seconds. As seen previously, error is incurred at small sample rates due to noise in data collection. To obtain reliable ramp rates from solar irradiance data, it is important to choose a sampling rate which falls between a minimum and maximum acceptable sample rate such that the minimum does not incur error due to the particular system's internal noise, and the maximum yields acceptable precision per the difference method used.

Another visualization of the change in ramp rates with respect to sample rate is shown below in Figure 71. Here, the ramp rates are calculated for a given sample rate then arranged large to small to provide a representation of the duration of large ramp rates. Though the red line ends as it encounters the x-axis, ramp rates may not be zero the remainder of the hours, but are sufficiently small to neglect. Notice, as the sample rate decreases, not only does the maximum ramp rate (y-intercept) increase, but more moderate and small ramp rates are evident.





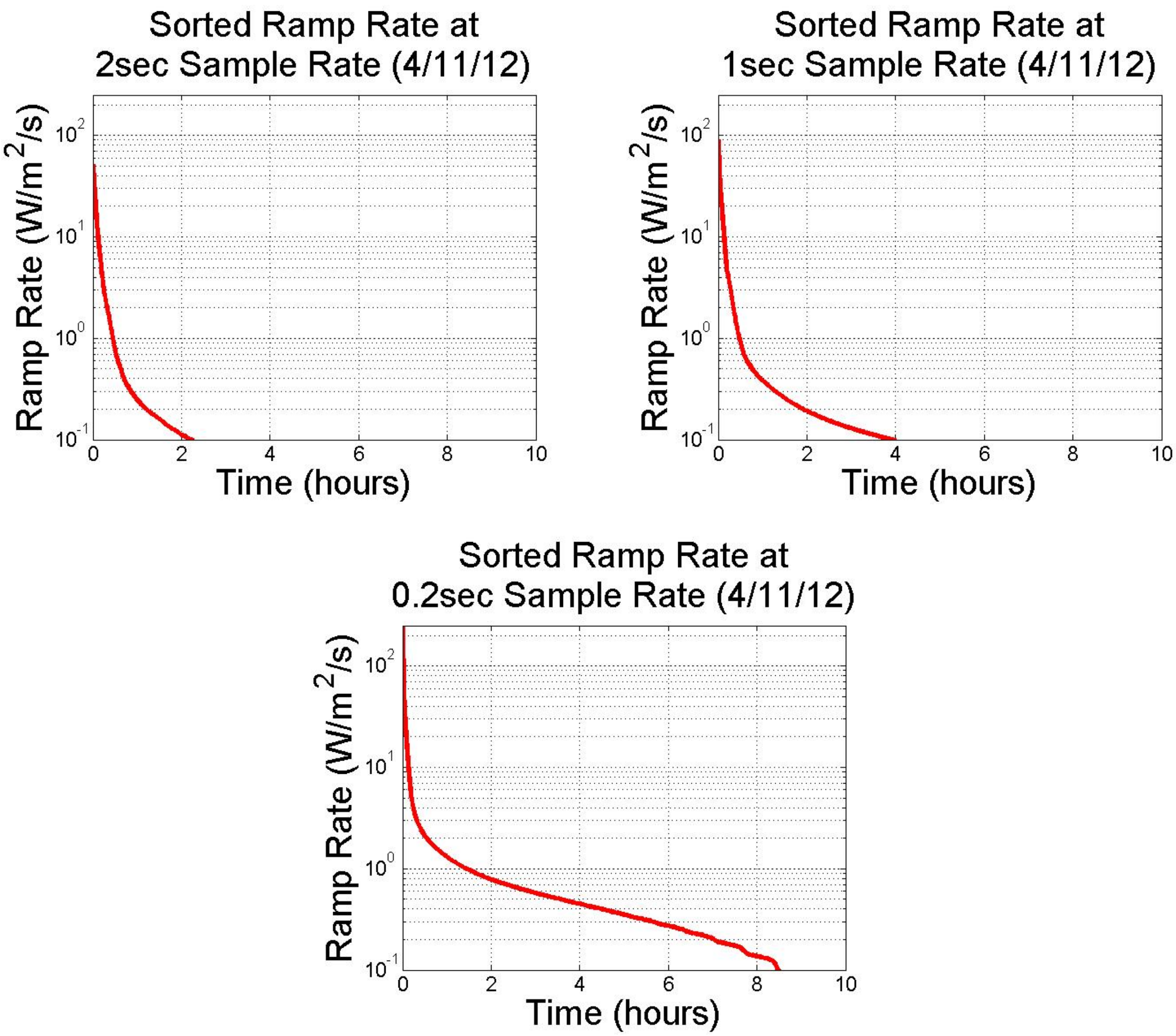


Figure 71 - Sorted Ramp Rates versus 24-hour Period

4.9.3 Conclusions

After performing this analysis, one could conclude that a 4th order difference method at a one second sampling rate would be sufficient for ramp rate calculation depending on the required response time for a smoothing battery bank. This method provides reliable ramp rates which have minimal effects of noise and also don't span such a large time interval that the result averages some of the genuine variability. In a real-time situation however, another method would have to be used which depends solely on present and past irradiance data.

Some further steps in this analysis include testing more data sets with varying degrees of variability. Also, the effects of different data collection should be explored. For example, in this analysis, data was taken from a single roof-top sensor. It should be noted that this data collection method could exhibit higher ramp rates than if one took the average of an array of sensors placed around a solar array. This would more closely correlate with the total output power of the array.

4.10 Irradiance vs. Percent Cloud Cover Results

The predicted clear day irradiance data for a given day and sample rate were obtained using well-known geometric equations coupled with air mass attenuation models [1]. The calculations also provided the angle of incidence necessary for finding the normal component of irradiance impinging on fixed plate collectors. For the solar array's latitude, longitude, altitude and orientation, the theoretical terrestrial clear-day direct-beam irradiance plotted over the year is represented in Figure 72 for a South-facing surface tilted at 25˚.

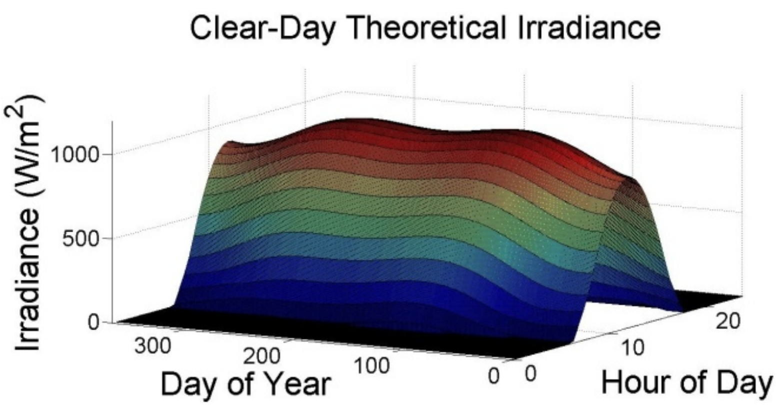


Figure 72 - Clear-Day Theoretical Irradiance; for array's location and orientation

The contributions of secondary effects, such as diffuse irradiance, air mass attenuation and local to solar time adjustments based on location with respect to the local time zone's standard meridian were also considered. More specific to this site, adjustments were made to account for a hill just east of the array which caused a delay in apparent sunrise every morning. As an example of prediction accuracy for a clear day, consider a single day's irradiance data (September 23, 2011) shown in figure 3a. It is difficult to see the difference between nearly overlapping lines. To show consistency, a separate day (October 20th, 2011) is shown directly below in Figure 74.

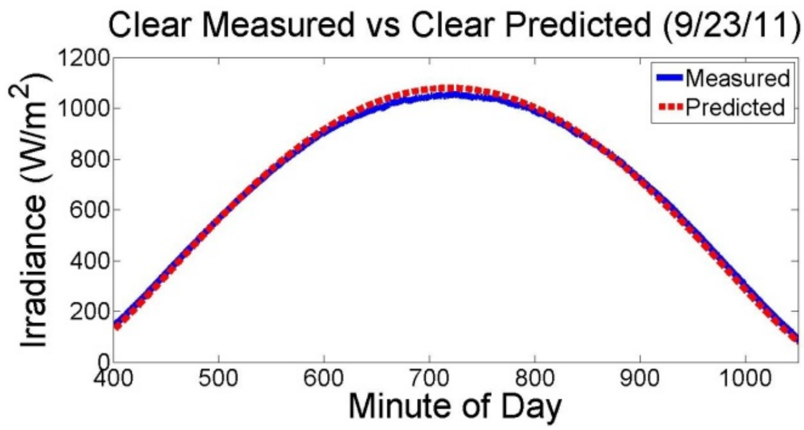


Figure 73 - Clear Day's Irradiance (9/23/2011) vs. Clear Day Prediction

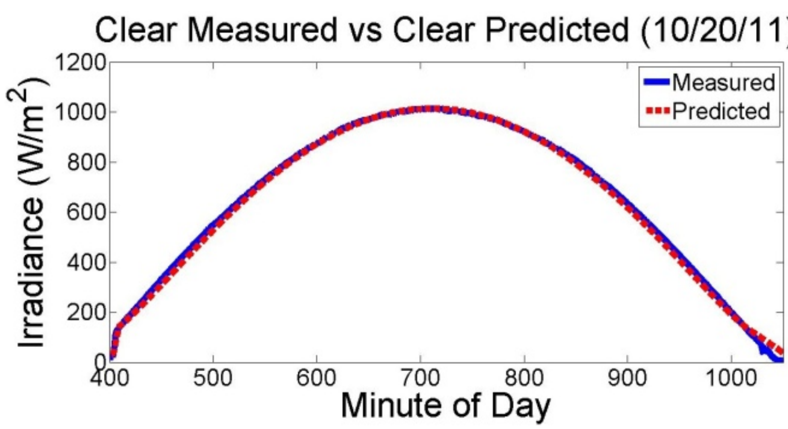


Figure 74 - Clear Day's Irradiance (10/20/2011) vs. Clear Day Prediction

Historical day-ahead predictions of percent cloud cover were made available by the NWS. For these predictions, the NWS makes a prediction of 0, 20, 50, 80 or 100 percent cloud cover at times 9:00am, 12:00pm, 3:00pm and 6:00pm. These values were interpolated over the entire day's samples using a cubic spline interpolating function. Checks were also put in place to ensure no percentages exceeded 100% or became negative.

After modifying the clear-day curve in figure 2 according to equation 2, the year's irradiance predictions show sharp drops where percent cloud cover predictions are available.

$I_{Prediction} = I_{ClearDay}\left(1 - k\left(\frac{\%\ Cloud\ Cover}{100}\right)\right)$ (Equation 2)

Shown below in Figure 75 is the resulting prediction plot with cloud cover. Continuously smooth, unaltered curves are present where NWS data were either unavailable or 0% cloud cover and steps down indicate cloud cover.

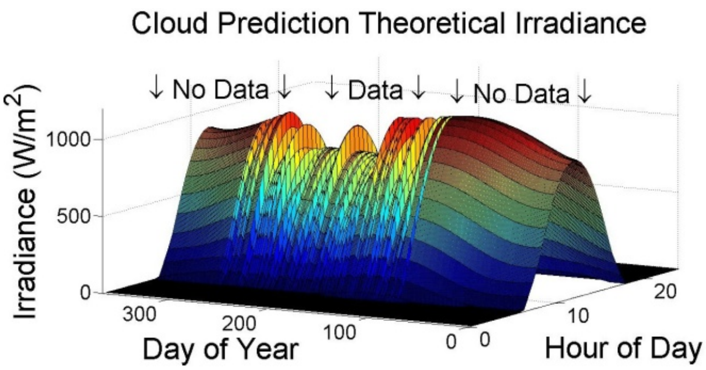


Figure 75 - including cloud cover; original curve unchanged where data unavailable

For a closer look, September's predicted irradiance curve appears as the plot below. Comparing to previous figure in Section, high percent cloud cover was predicted early in the month, corresponding to measured irradiance. Later in the month, when there were clear skies, the NWS predicted light cloud cover, suggesting conservative forecasting.

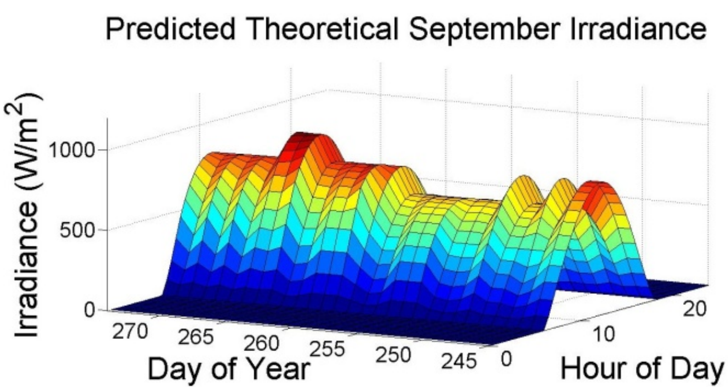


Figure 76 -September's Prediction; compare lower curves to spikes in figure 1a

Smooth behavior on a cloudy day is not realistic and should not be used for real-time control, but may be inevitable for day-ahead planning. Consider, for example, September 10, 2011 which was a cloudy day with NWS predictions to match. The following comparison (zoomed in for detail) shows actual irradiance versus predicted irradiance.

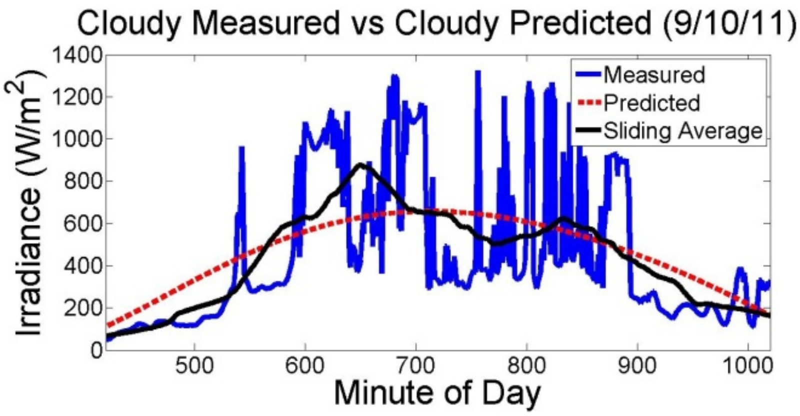


Figure 77 - Cloudy Day's Irradiance (9/10/2011) and Sliding Average vs. Prediction

As an overall comparison of the measured and predicted irradiance values, a one-to-one scatter plot was generated. If compared to a perfect prediction method, all data points would be located on a line at 45 degrees from the origin (i.e. y=x).

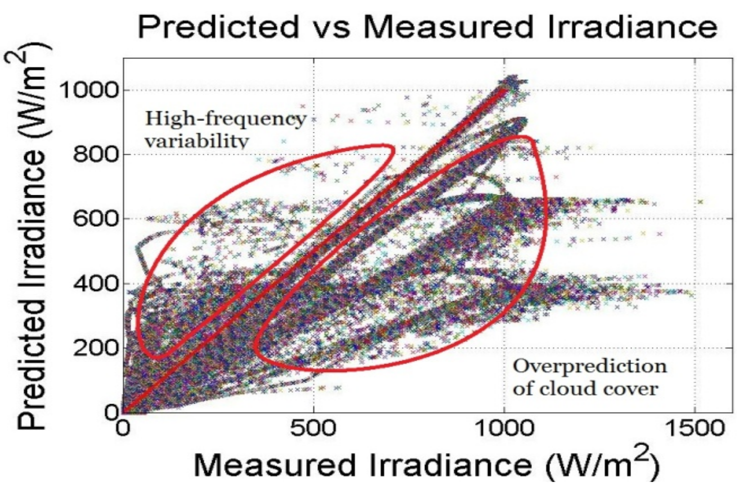


Figure 78 -Cloudy Day's Irradiance (9/10/2011) and Sliding Average vs. Prediction

The scattering around the y=x line is due to cloud cover. The three line patterns, shown flowing low and right of the y=x line, are days where a prediction greater than zero percent cover was made, but the array experienced clear day irradiance. Moving away from y=x, the lines correspond to 20%, 50% and 80% cloud cover predictions.

One of the user determined characteristics in this analysis was the effect of cloud cover resulting from the constant k in equation 2. Considering this, secondary lines were added at 34 and 60 degrees out from the origin to help center the data cloud equidistantly from x-coordinate of the y=x line. This means for a predicted irradiance (e.g. 600 W/m^2) we have an equal range of irradiance above and below the predicted value. The resulting centering generated the plot in Figure 79 below.

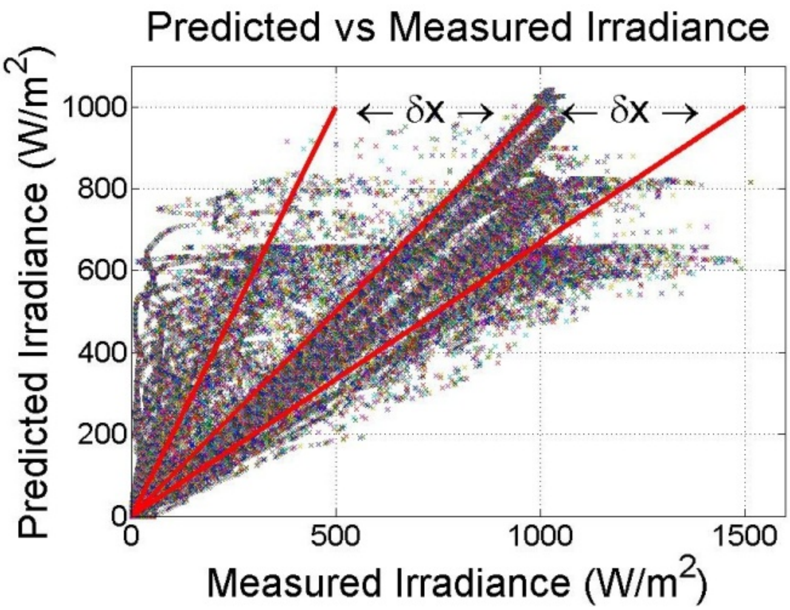


Figure 79 - Centered Predicted vs. Measured Irradiance; average distribution of scatter

The sliding average of the measured data provides further clean-up by removing many of the large spikes seen in measured data. This also yields clear path lines for specific days' sliding average irradiance curves.

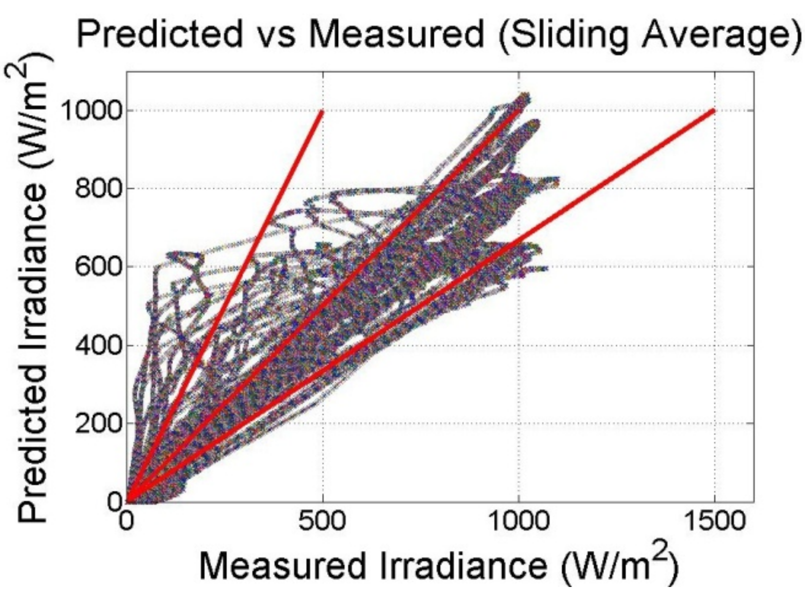


Figure 80 - Predicted vs. Sliding Average of Measured Irradiance

For a closer look, Figure 81 compares two days' irradiance. The line nearly coincident with the y=x line is a clear day and the scattering black path and green looped path are a cloudy day's measured and sliding average irradiance, respectively.

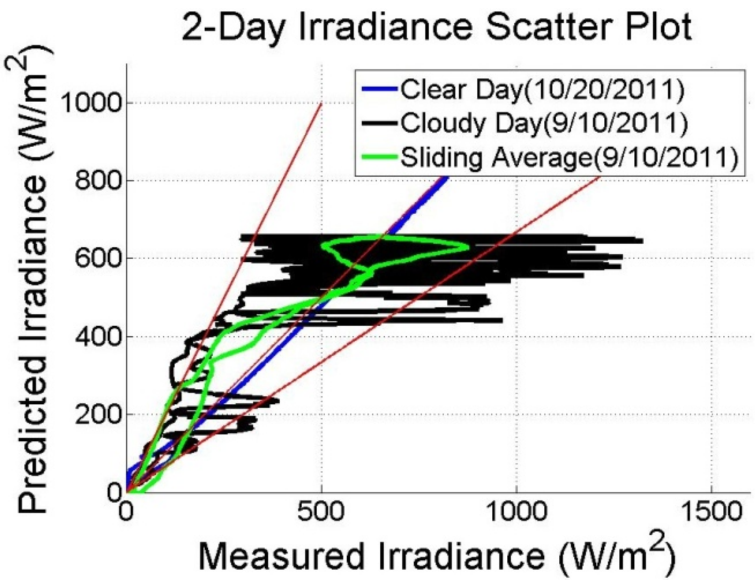


Figure 81- Clear and Cloudy Day Comparison

One test of this algorithm may include adjusting the data cloud or cloud cover weighting based on total energy for the day. A preliminary energy comparison was done by calculating the area under both theoretical and measured irradiance curves, producing Figure 82 below. The scatter low and right of the red line suggests that the prediction is too low. However, this is largely due to over-predicted cloud cover by the NWS.

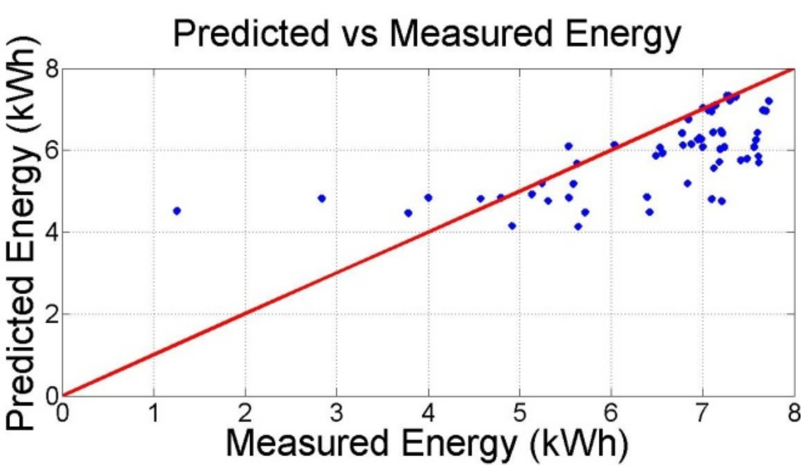


Figure 82 -Predicted vs. Measured Energy per day; over-predicted cloud cover evident

Testing is ongoing for this irradiance prediction method. Once this prediction method is perfected to within an acceptable reliability, predictions can be checked against the solar array's different irradiance sensors located at different corners of the array. This would ideally provide an immediate prediction of impending irradiance based on cloud-level, wind direction and cloud cover.

5 Grid Impacts and Benefits

5.1 Actual Benefits

At this early stage PNM has not yet calculated grid impacts and quantified benefits derived from the project. These will be assessed in later stages, and the current efforts are targeted at assessing the benefits listed the MBRP which follow.

5.2 Projected Benefits from Project MBRP

The benefits estimated for PNM's demonstration project will be evaluated using three of the four DOE-specified major benefit categories: 1) Economic, 2) Environmental, and 3) Security. PNM does not anticipate reliability benefits to be claimed by this project.

The main benefits expected from the demonstration include deferred generation capacity investments and deferred distribution capacity investments. Benefits can be derived through the avoided costs of substation or feeder expansion due to peak shaving and avoided cost of capacitor banks and voltage regulators by smoothing PV ramp rates and minimizing voltage fluctuations. Creation of a reliable, dispatchable renewable resource is also intended to account for pollutant emission avoidance.

Optimized Generator Operation - These benefits are enabled by the shifting function of the demonstration. Specifically various algorithms will be designed, tested through computer modeling and implemented in the test plan to determine the best mode of creating a firm, peaking, renewable energy resource.

Deferred Generation Capacity Investments –These benefits are attributed to the ability of the system, as a firm peaking resource, to allow avoidance of fossil based peaking resource additions. By establishing a firm resource from PV a much higher capacity factor can be allowed these systems in resource planning. Benefit will be measured by success of targeting a elevation of the peak contribution of PV (from 55% current to 90% - typical of a gas peaking unit).

Deferred Distribution Capacity Investments (utility/ratepayer) –These benefits are enabled by the smoothing function of the demonstration. The smoothing function will alleviate voltage swings and avoid extra distribution system protection. The cost of required protection for an unsmoothed system will be stacked with other benefits

Reduced Carbon Dioxide Emissions (society) Substitution of fossil fuel based generation with PV may reduce carbon dioxide emissions. Establishing the amount of such reductions requires:

1) tracing the load profile of the load change attributed to the project back to ascertain how the generation dispatch was affected, 2) determining which generation units had their output reduced (and which had their output increased, if appropriate), and 3) associating with each affected generation unit a CO_2/kWh emission rate.

Reduced SO_X, NO_X, and PM-2.5 Emissions (society) - Establishing these emissions effects involves tracing the load profile to the generation origin method, as is required for CO2 impact, but in this case the effected generation output is associated with an SO_X, NO_X, and PM-2.5 Emissions rate

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Summary of SGDP Metrics to be Reported	
Build Metrics	**Impact Metrics**
• Monetary Investments • Jobs Created and Retained • Policies and Programs • Electric Distribution System Assets • Distributed Energy Resources	• Electric Distribution Systems • Storage System

Table 7 PNM Build and Impact Metrics Summary

6. Major Findings and Conclusions

6.1 Dead Band Needed in Shifting Algorithm

As the shifting algorithm was introduced, spikes were generated because the algorithm did not have an adequate dead band when it looked at battery SoC and then instructed output. Once a dead band was introduced the spikes were removed.

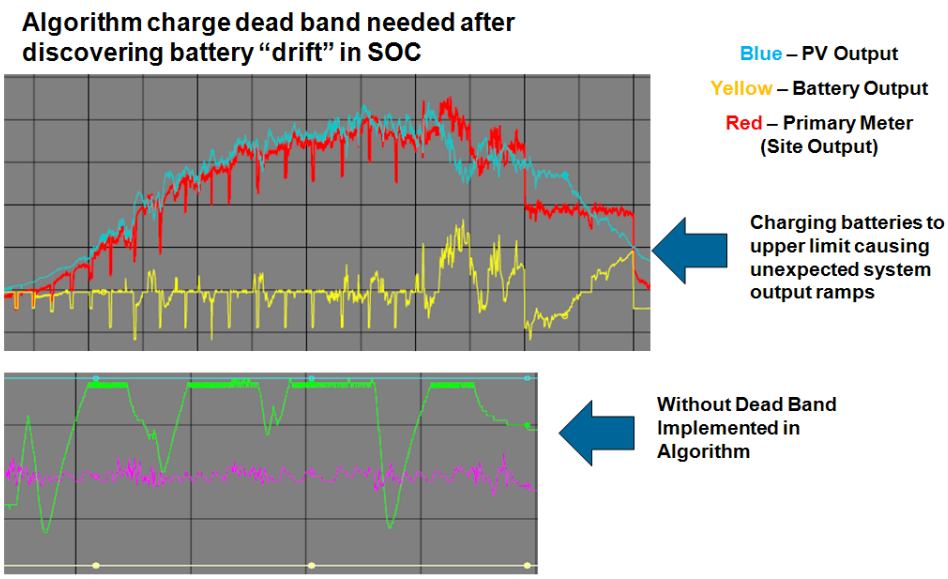


Figure 83 - Shifting without dead band

6.2 Firming with Clouds - Simultaneous Smoothing and Shifting –

As presented in Section 4.3, challenges exist in delivering a firm PV energy output from the shifting batteries during heavy cloud cover while the smoothing batteries are in operation. Because firmed energy must be delivered with a high level of confidence, in order to maintain the level of confidence the output delivered may need to lowered. One solution path will entail looking at the predicted cloud cover and mitigating the amount of firmed kW, but keeping the delivered kWh intact. This involves lowering the height (kW) of the firmed PV product but also broadening the delivery time to produce a more confident oriented target shape, see Figure 84. Correlation models have already been developed that will feed into the shifting algorithm the amount of energy

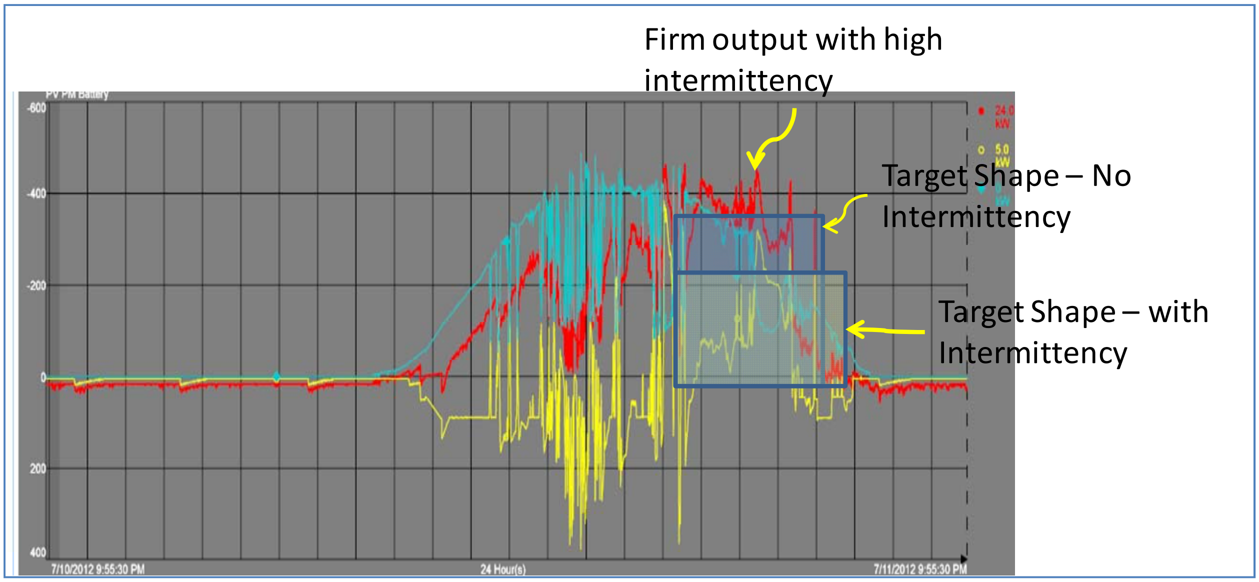


Figure 84 - Firming Targets with and without Intermittency

6.3 Ramp Rate Analysis - HVAC Noise Filtering -

During warm weather the cycling of battery HVAC units in the battery containers introduces a ripple effect on the primary meter, evident in Figure 85. This noise can affect the ramp rate analysis, see below, but can be mitigated by factoring out the specific kW meter readings of the single phase meter serving the HVAC units. Register problems with this meter have prevented proper values from being sent to the database. Once solved, the data from this meter can be mathematically subtracted from the primary meter in ramp rate via statistical analysis techniques.

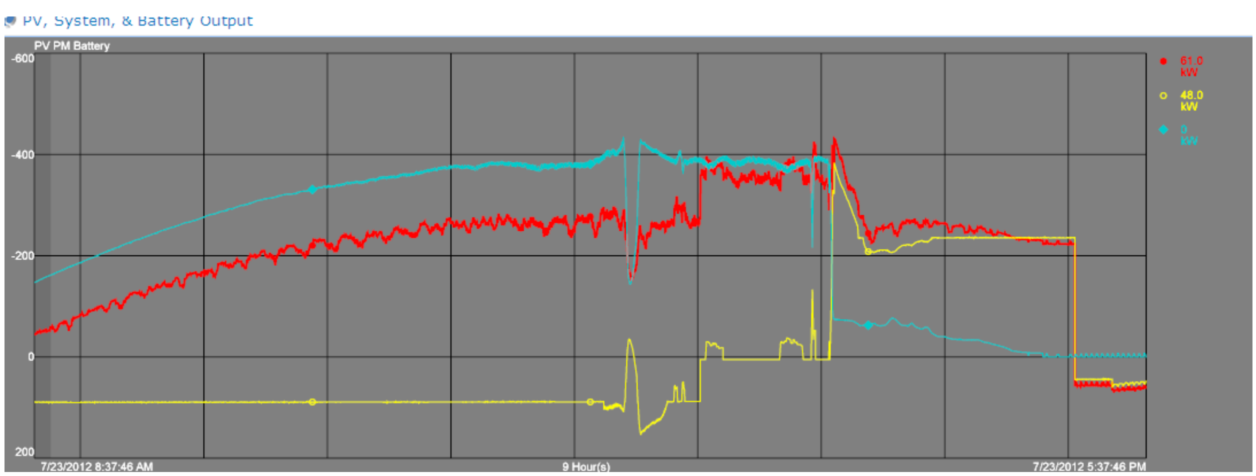


Figure 85 - Sample showing HVAC ripple effect

6.4 Ramp Rates Definition and Mitigation Analysis

Lack of true mathematical definition of ramp rate has been a challenge as has been the uneven time sampling inherent in the PI database collection of data. The project offers many exciting opportunities for data-driven analysis of ramp rates. There is the technical problem of deriving and implementing a fast, on-line real-time Savitzky-Golay filter for unevenly sampled data. This will provide real-time ramp rate calculations. A refined approach to ramp rate analysis is discussed in the section 7.

6.5 Smoothing Adequacy

A key question is “how much smoothing is enough?” Understanding how much smoothing is sufficient involves optimization analysis that positions the smoothing results of different smoothing battery capacities against status quo solutions to PV intermittency, see Figure 86. These status quo solutions could include addition of voltage regulators and/or capacitor banks along with implementation of load tap changers to track and adjust voltage. Where load tap changers exist it could involve enhanced operation and wear and tear. It is visually apparent from Section 4 that 10% of the battery capacity invokes little to no effect while 40% of the battery capacity has some effect but the PV intermittency is really smoothed, visually, when 70% or greater of the smoothing battery capacity is utilized.

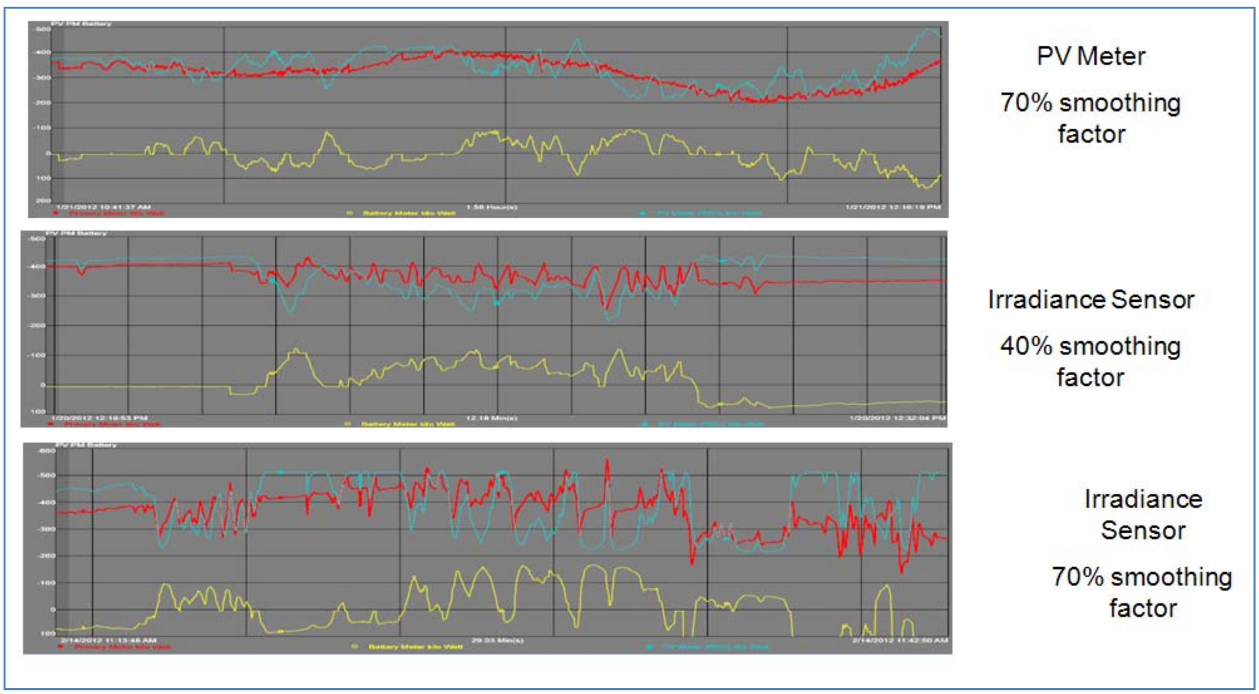


Figure 86 - various smoothing results utilizing different inputs and battery capacities

6.6 Lack of Correlation with Current Forecast Used for Shifting

The only currently available forecast for predicting PV production for the shifting algorithm is the NWS % Cloud Cover prediction, Figure 87, which is made in 4 hours blocks for the next 2 days. Sections 3 and 4 detailed analysis and results that shows the % cloud cover forecast does not correlate well to cloudy day but does work on clear days, see Figure 88. This lack of correlation drives a distinct need for a better PV related forecast.

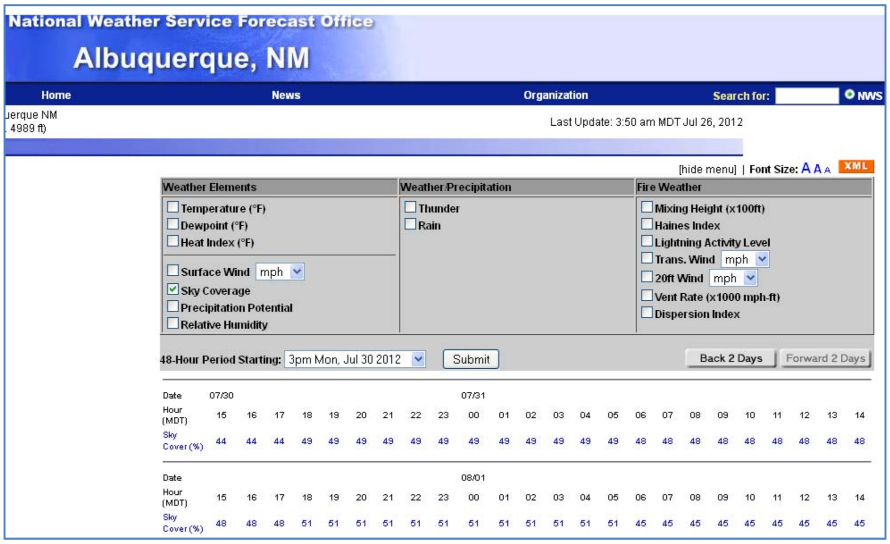


Figure 87 - Snapshot of NWS Cloud Cover Forecast

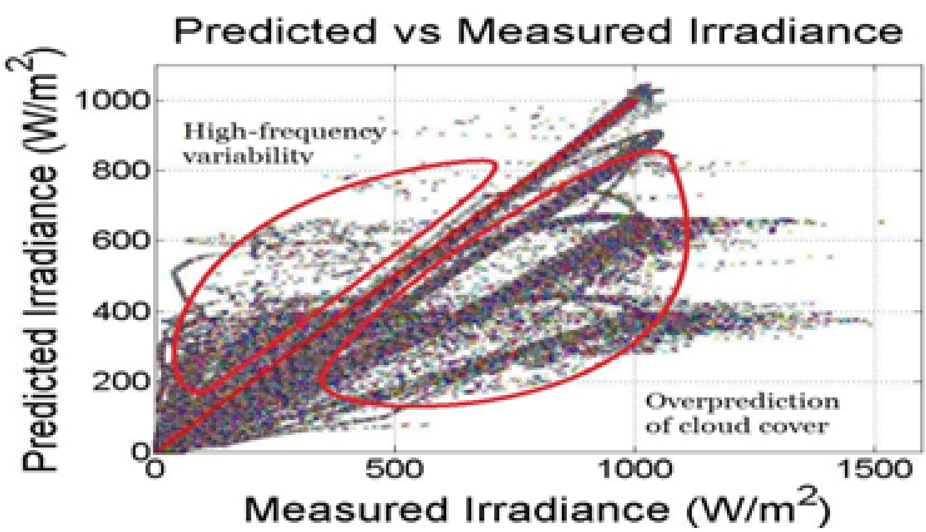


Figure 88 - Correlation analysis of NWS forecast and actual PV energy production

6.7 Need for Hour Ahead PV forecasts

Models have been run at UNM that potentially show that a forward moving average smoothing algorithm would mitigate use of the smoothing battery and show similar results – see Section 4.

In order to utilize a forward moving average a hour ahead prediction of PV production or cloud cover (with a related engine converting the results to PV output) would be required. An upwind PV installation could similarly serve as a predictor assuming it consistently is experiencing clouds prior to the PNM Prosperity site at a set time window.

6.8 Need for Day or 2 Day Ahead Forecast

The loss of confidence in the amount of power output that the shifting algorithm can instruct belies the need for an accurate day and 2 day ahead forecast; the more reliable the forecast the more power and higher y axis (kW) shape the firmed energy product can take.

6.9 PV Meter vs Irradiance Sensor

A lack of linearity between the irradiance sensor and PV output was observed. This is due to the fact that the inverter has a maximum output (500kW) while the irradiance meters are based purely on the amount of insolation. At certain times the irradiance will climb to very high values (~1300W/m2) and the PV output will peak at 500kW. Using the irradiance as a control input can, in these cases cause to the smoothing battery, to over produce and spike above the PV output, negating the smoothing effect. The PV meter as a control input overcomes this issue. The lack of correlation and linearity between the PV and Irradiance on these high output days were the PV inverter is maxed out is evident in Figure 89. It should be noted also that the PV inverter does a small amount of smoothing as well through its MPPT electronics. This furthers the lack of linearity in that it PV does not strictly follow the ramps of the irradiance because there is ancillary electronics in the inverter that affect the DC power in conversion to AC power.

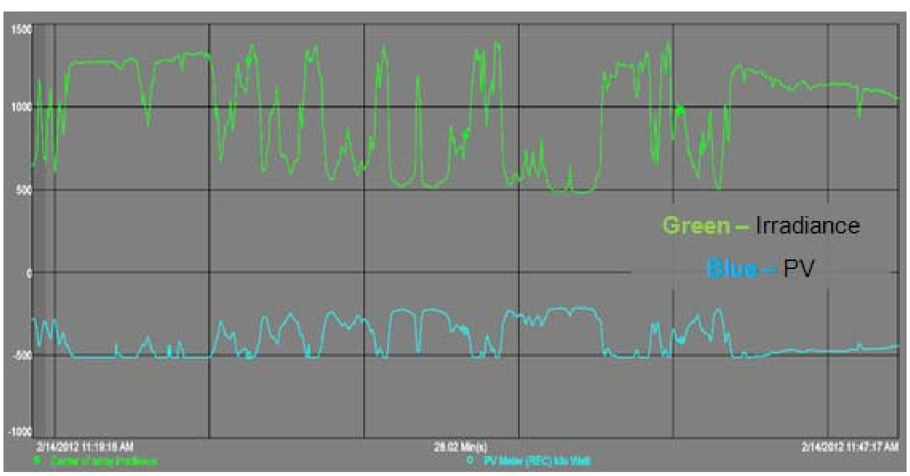


Figure 89 - Irradiance vs. PV Plot

6.10 Latency Issues in Smoothing

Section 4 presented analysis showing the timing of signals received by the DAQ gateway and then delivered to the BESS for smoothing. The analysis was conducted when the smoothing battery was spiking by responding too late to PV down-ramps and subsequent up-ramps. Latency was apparent in the threshold used by both the PCS and BESS functions. When these thresholds were tuned, in a systematic fashion, the system response was greatly improved. If a systematic approach was not used the root cause may not have been identified and mitigated.

6.11 Choosing Smoothing Algorithm Window Size

A key tradeoff exists between the amount of smoothing applied and the lifetime of the battery. The lag between the original figure and smoothed figure is half of the window size. The larger window size means smoother result, but also means larger lag. The larger lag will induce a greater change in SoC and consequently increase battery energy consumption. The lifetime of battery is determined by the cumulative energy used, therefore a larger window size means shorter lifetime of battery. Optimizing on an appropriate window size is a key issue for the smoothing algorithm

6.12 Sensitivity of PV System - Ramp Rates Measured

The PV site associated with this project appears to be extremely sensitive to cloud intermittency. This could be due to the intermediate size of the system (500kW), the panel types (Poly Si) and the relatively low geographic spread (4 acres). Severe ramp rates have been recorded up to 130kW per second ramps on this system. Nevertheless the smoothing battery is apparently capable of mitigating these large ramp rates, see Figure 90.

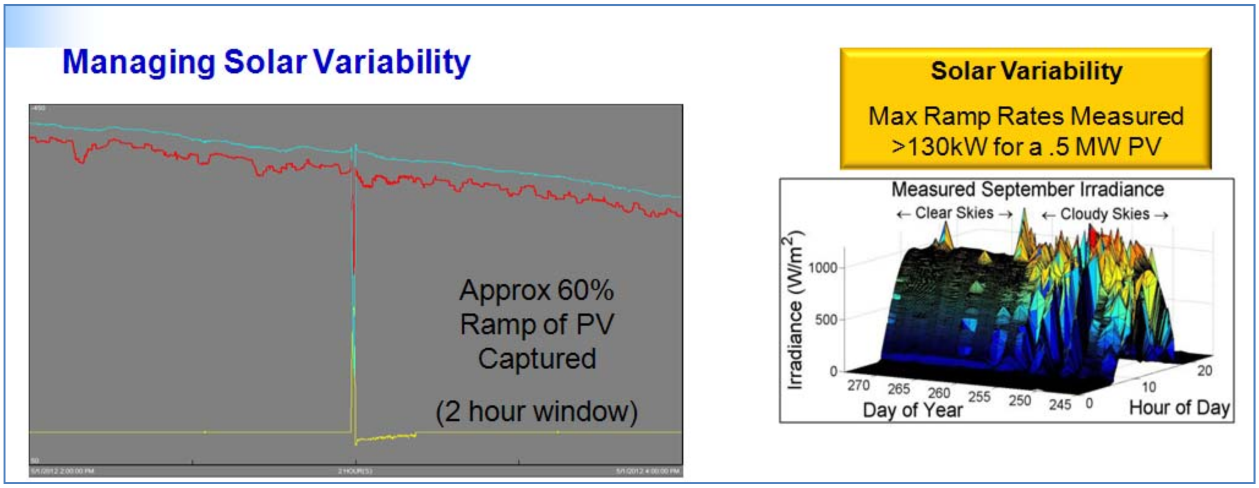


Figure 90 - Severe ramp rate capture data

6.13 Primary Meter as a Smoothing control input.

This configuration was informally tested but showed that a feedback loop was introduced and the resultant smoothing was not effective.

6.14 Power request vs Actual Power output of PCS

A power request tag was created in the PNM PI system to send a control signal to the shifting register in the battery controller. It was found that the power request from PI system did not correlate with the actual output. A test was performed sending the power request at 200kW and observed 191kW & 177kW see Figure 91. This was resolved through PCS internal software updates.

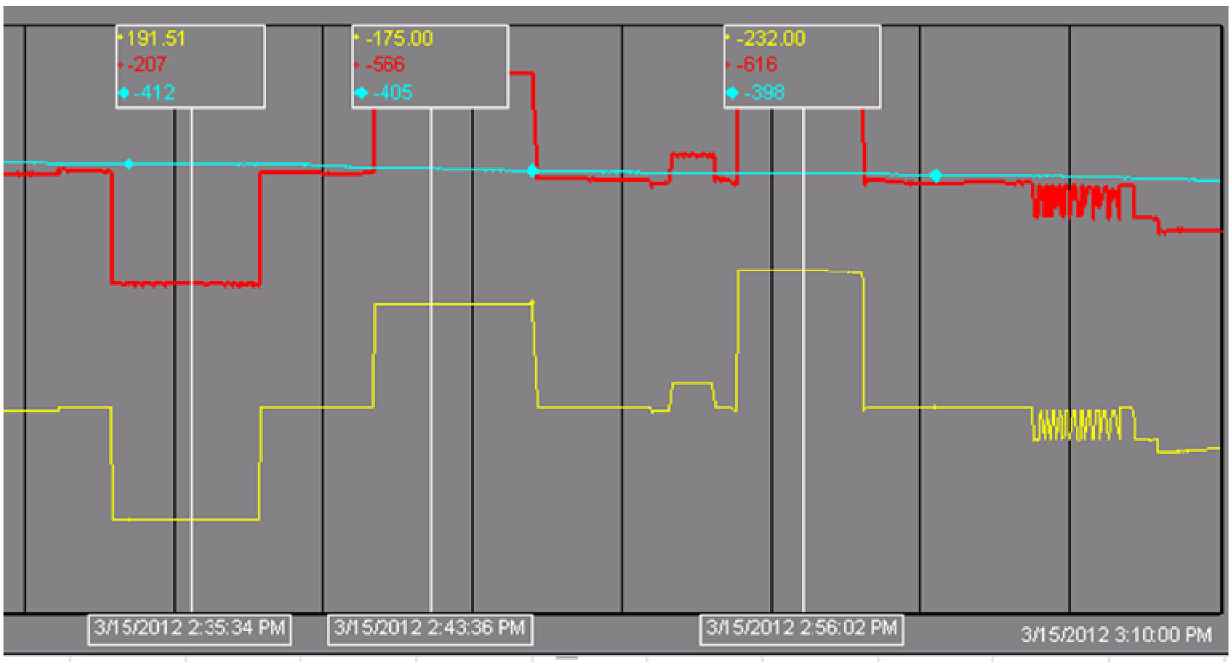


Figure 91 - Detail data on power request vs output power

7 Next Steps

7.1 Test Plan 1 modifications

Test Plan 1 will be modified to incorporate test of the Low Pass Filter instead of the averaging function, as well as incorporate a forward moving average, incorporation of PNM ACE (or proxy) and utilization of other external signals to the smoothing algorithm, including a predictive PV signal from Los Morros. These efforts are discussed further, below.

7.2 Simultaneous Smoothing and shifting

More work is needed to accommodate the shifting and smoothing and the roles each algorithm should perform. In recorded data we have large values in the battery meter output. This is combination of both the shifting and smoothing acting on the PV intermittency. Some algorithm improvements are needed here so that both algorithms don't target this simultaneously. It may also require some investigation on whether it's suitable to have two interdependent algorithms in two locations, i.e. smoothing in the BESS and shifting in the PNM ACE due to latency considerations.

Another solution path could entail looking at the predicted cloud cover and mitigating the amount of firmed kW, but keeping the delivered kWh intact. This involves lowering the height (kW) of the firmed PV product but also broadening the delivery time to produce a more confident oriented target shape. Correlation models have already been developed that will feed into the shifting algorithm the amount of energy

7.3 Shifting automation

Correlation models have already been developed that will feed into the shifting algorithm, the amount of PV energy available next day, based on the % cloud cover prediction from NWS. Further work, related to the above effort, is envisioned where thresholds are built into the algorithm such that below a certain predicted % c loud cover a clear day is assumed. Above the lower threshold the analysis will establish higher thresholds where certain amounts of energy will be confidently predicted.

7.4 Ramp rates definition and mitigation analysis

After collecting additional data across multiple test plans the ANOVA/ANCOVA procedures will be employed for deriving models for the ramp rates. This will allow us to determine what the main factors are in smoothing a PV signal. But, this is not an end in itself. Rather, the developed model will be used to derive the *economically* optimal smoothing procedure. It is not enough to try for maximal smoothing if the cost of that achievement is high. Rather, one needs to balance the advantages of smoothing against the costs of achieving that degree of smoothing. Because of this, we will derive a cost function that includes items such as battery cost and dollar benefits from smoothing. These will depend on the variables used in the ANOVA/ANCOVA. Now we can change the levels of the independent variables and weigh these against the degree of smoothing achieved.

7.5 Smoothing adequacy – optimization analysis

Solving for the optimal amount of smoothing needed in a high penetration PV environment will be site dependent. Given that the feeder supporting the project is not yet at a high penetration of PV level optimization analysis will need to rely on OPenDSS and/or GridLAB models. This will turn to an economic optimization analysis where the benefits of increased levels of smoothing are compared to the status quo costs of not having smoothing. These status quo costs will be derived from what the models require in a high penetration environment, including addition of voltage regulators, capacitor banks and transformers with load tap changers, or in the case where these already exist, increased wear and tear. Modeling will also allow varying degrees of penetration to be looked at as well as different types of PV (thin film vs PolySCi vs CPV)

7.6 Need for an hour ahead PV forecasts

A potential effort would incorporate a forward moving average in the smoothing algorithm. Models already show that this approach would diminish the amount of energy used by the smoothing batteries. In order to pursue this approach a predictive signal would be needed. Two options are apparent. The first would be importing the output signal from an upwind PV Site owned by PNM (Los Morros). This signal would also need to be coordinated with site wind speed and wind direction to ascertain the signal from this site is predicting accurately and is indeed upwind. This signal would come across PNM's SCADA system and would have to be imported into PI. A second option would entail getting an hour ahead signal from a industry based effort. PNM is currently participating in a industry collaboration proposal that seeks this kind of forecast development.

7.7 Need for Day or 2 Day ahead forecast

As the smoothing algorithm needs an hour ahead forecast the shifting needs an accurate day and 2 day ahead forecast in order to create a high level of confidence that the amount of firmed energy will be available. Even though site has 167 clear days/year it is still important to have an automated prediction engine. This may come through project partner specific development – based on discussion above on looking at thresholds of % cloud cover or through the industry collaboration effort, also mentioned above.

7.8 Choosing smoothing algorithm window size

The window size will need to be selected depending on current weather conditions. If a day is sunny, without any cloud cover, it may not be needed to use the Battery smoothing system at all. But for a cloudy day, the window size should be selected based on the severity of cloud cover. The relationship between the window size and smoothness improvement need to be explored further. Weather forecast can be used to adjust window size based on weather conditions and current energy priorities. This will be part of our future research

7.9 Incorporation of external inputs into smoothing algorithm

7.9.1 ACE from PNM

Test Plan 1 contemplates sending a signal from PNM ACE to PI then to one of the AUX inputs in the smoothing algorithm. There may be FERC/NERC policy issues that need to be addressed and its not clear these policies allow the signal to be sent to a non-transmission asset. If policy issues are not surmountable a proxy signal set will be developed and utilized.

7.9.2 Signal from NEDO Project

NEDO (Japanese Trade Organization) has constructed a smart grid project adjacent to the Prosperity Site at Mesa del Sol's Aperture Center. The NEDO project consists of a fuel cell, gas generator, thermal storage, PV cells, battery and a smart grid oriented control system. NEDO endevours to study the interaction of the gas generator with an aim to increasing overall system effectiveness of reducing PV output ramps by using a gas generator combined with the Prosperity smoothing battery. The target is minimized battery operation and reduced battery size needed for a given application through co-utilization of the gas generator

7.10 Evolve control architecture to DMS

As the shifting algorithm evolves and external signals are driven from forecasts and PNM operations, the ultimate control system will need to contemplate operation with these advances and the capability of controlling numerous DER. Figure 92 below shows the vision associated with this effort, which is outside the DOE scope.

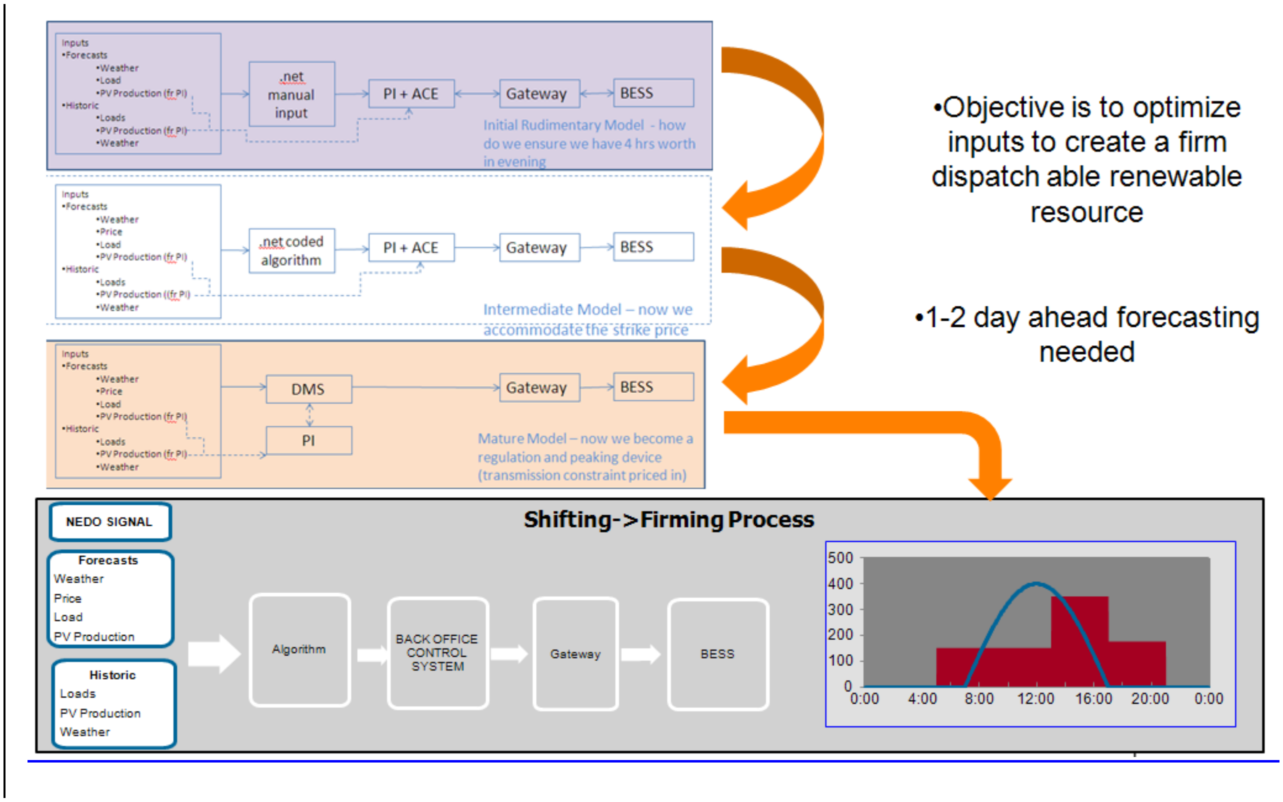


Figure 92 DMS Vision

7.11 Peak Shaving

Test Plan 3 contemplates utilizing a substation and /or feeder signal to perform peak shaving. This effort is similar to the firming effort under Test Plan 2 which is underway. It will utilize a modified version of the shifting algorithm but use SCADA based signal from PNM.

7.12 Incorporation of Price Signal into Shifting Algorithm.

Test Plans 4 and 5 both contemplate sending price signals to the control algorithm. The project will extract ICE Palo Verde or 4 Corners price day ahead forecast and created hourly weighted price forecasts by introducing hourly pricing factors.

Appendix A - Points List

PI Name	Point Name	Point Description	FAT Comment
		Cooper	
	CR3000_	CR 3000	
CR3000_inverter_current_1a	inverter_current_1a	Current L1-A	AAD
CR3000_inverter_current_1b	inverter_current_1b	Current L1-B	AAN
CR3000_inverter_current_2a	inverter_current_2a	Current L2-A	AAD
CR3000_inverter_current_2b	inverter_current_2b	Current L2-B	AAD
CR3000_inverter_current_3a	inverter_current_3a	Current L3-A	AAD
CR3000_inverter_current_3b	inverter_current_3b	current L3-B	AAD
CR3000_inverter_voltage_1	inverter_voltage_1	Voltage 1	AAD
CR3000_inverter_voltage_2	inverter_voltage_2	Voltage 2	AAD
CR3000_inverter_voltage_3	inverter_voltage_3	Voltage 3	AAD
CR3000_wiring_panel_voltage	wiring_panel_voltage	cr3000 wiring panel voltage	AAN- not passed to pnm, posi. Energy only
CR3000_watchdog	watchdog	watchdog timer	AAN- not passed to pnm, posi.

			Energy only
CR3000_met_rh	met_rh	met relative humidity	AAD
CR3000_met_temp	met_temp	met temp	AAD
CR3000_met_windspeed	met_windspeed	met wind speed	AAD
CR3000_met_winddir	met_winddir	met wind direction	AAD
CR3000_met_irr	met_irr	met irradiance	AAD
CR3000_met_sw_irr	met_sw_irr	Li-Cor Pyranometer SW Corner	AAD
CR3000_met_sw_temp	met_sw_temp	Temp Sensor SW Corner	AAD
CR3000_met_se_irr	met_se_irr	Li-Cor Pyranometer SE Corner	AAD
CR3000_met_se_temp	met_se_temp	Temp Sensor SE Corner	AAD
CR3000_met_nw_irr	met_nw_irr	Li-Cor Pyranometer NW Corner	AAD
CR3000_met_nw_temp	met_nw_temp	Temp Sensor NW Corner	AAD
CR3000_met_ne_irr	met_ne_irr	Li-Cor Pyranometer NE Corner	AAD
CR3000_met_ne_temp	met_ne_temp	Temp Sensor NE Corner	AAD
CR3000_met_cent_irr	met_cent_irr	Li-Cor Pyranometer center of array Corner	AAD
CR3000_met_cent_temp	met_cent_temp	Temp Sensor center of array Corner	AAD

	BESS_	BESS	
	INTLRPTR_	Intellirupter	
	PM_MTR_	PM Meter	
PM_MTR_kw	kw	kilo Watts	AAN
PM_MTR_kvar	kvar	Reactive Power (kvar)	AAN
PM_MTR_kv	kv	Volts (kv)	AAN
PM_MTR_kwh	kwh	Kwh	AAN
PM_MTR_freq_hz	freq_hz	frequency	AAN
	PV_MTR_	480V xfmr PV meter	
PV_MTR_kw	kw	kilo Watts	AAN
PV_MTR_kvar	kvar	Reactive Power (kvar)	AAN
PV_MTR_kv	kv	Volts (kv)	AAN
PV_MTR_kwh	kwh	Kwh	AAN
PV_MTR_freq_hz	freq_hz	frequency	AAN
	BATT_MTR_	480V xfmr Battery meter	
BATT_MTR_kw	kw	kilo Watts	AAN
BATT_MTR_kvar	kvar	Reactive Power (kvar)	AAN
BATT_MTR_kv	kv	Volts (kv)	AAN
BATT_MTR_kwh	kwh	Kwh	AAN
BATT_MTR_freq_hz	freq_hz	frequency	AAN
	120_240_MTR_	120/240 xfmr Meter (Veris 1 phase)	

	Prosperity_Primary_	SEL 351 (PMU)
		Primary Meter
		SEL 451 (PMU)
	Prosperity_	Battery Meter
	Prosperity_	PV REC Meter
	CGSTRNG_01_	Carlo Gavazzi String Monitor 1 (device ID = 4)
	CGSTRNG_02_	Carlo Gavazzi String Monitor 2 (device ID = 5)
	CGSTRNG_03_	Carlo Gavazzi String Monitor 3 (device ID = 6)
	CGSTRNG_04_	Carlo Gavazzi String Monitor 4 (device ID = 7)
	CGSTRNG_05_	Carlo Gavazzi String Monitor 5 (device ID = 8)
	CGSTRNG_06_	Carlo Gavazzi String Monitor 6 (device ID = 9)
	CGSTRNG_07_	Carlo Gavazzi String Monitor 7 (device ID = 10)
	CGSTRNG_08_	Carlo Gavazzi String Monitor 8 (device ID =

		11)	
	CGSTRNG_09_	Carlo Gavazzi String Monitor 9 (device ID = 12)	
	CGSTRNG_10_	Carlo Gavazzi String Monitor 10 (device ID = 13)	
	CGSTRNG_11_	Carlo Gavazzi String Monitor 11 (device ID = 14)	
CGSTRNG_11_F01_09_current	F01_09_current	String current F1-9	AAN
	webbox	Sunny Webbox	
webboxcumul_events	cumul_events	Consecutive number of cumulative events	AAN
webboxcurr_event_message	curr_event_message	Current event message	AAN
webboxop_status	op_status	Operational Status	AAN

Table 8 – Points List

Appendix B - Test Plans

8.2.1 PNM/DOE Test Plan 1 –

Revision History

Date	Version	Description	Author
3/29/11	1.0	Initial draft	Steve Willard
6/14/11	2.0	Updates from SNL	Bill Buckner

10/4/11	3.0	Update from PNM	Steve Willard
10/15/11	4.0	Updated from Ecoult	Brian McKeon
11/03/11	5.0	Re write from PNM	Steve Willard
11/21/11	6.0	Revision of test dates	Steve Willard
12/08/11	6.1	Revision of test dates and test labels	Steve Willard
1/11/12	6.2	Revision of test dates sub test 1BPV1	Steve Willard
1/19/12	6.3	Correction of test dates – remove 10% tests	Steve Willard
3/28/12	6.4	Correction of test dates – remove Primary Meter as input	Steve Willard
5/15/12	6.5	Remove 40% tests, limit use of irradiance sensors, institute 60, 80 and 100% tests	Steve Willard
7/2/12	7.0	Incorporate forward looking moving average time window	Steve Willard

1. Objectives
    a. Primary
        i. determine the optimum size of a Battery Energy Storage (BES) system vs amount of PV ramp rate mitigation provided for smoothing the power output of a 500kW PV system
        ii. determine the optimum algorithm for smoothing with respect to irradiance sensor versus PV and primary meters as the input control signal
        for maximum ramp rate mitigation

    b. Secondary
        i. Translate findings to UNM GridLAB and OpenDSS models to further optimize smoothing in high penetration feeders
        ii. Establish control path for sending ACE signal to BESS
        iii. Establish methodology of automatically polling NOAA website for cloud cover prediction and incorporating into a database for algorithm use
        iv. Correlate NOAA predictions to associate % cloud cover with cloud types
        v. Balance battery capacity used vs. optimized voltage regulation for various cloud types
2. Scope/Requirements

   a. In Scope – East Penn CUBs smoothing function and CUB BESS, 500kW PV system, beginning and end of 12.47kV distribution feeder configurations
   b. Out of Scope – East Penn CABs shifting function
3. Roles & Responsibilities
   a. Ecoult/East Penn – trigger battery operation, establish and refine control settings, provide UNM battery model parameters, provide optimized algorithm through continual feedback of test results
   b. PNM – provide operational system, data and system access
   c. Sandia National Labs– monitor demonstration and provide technical input
   d. UNM – provide modeled results and modify models as needed to match actual recorded demonstration data, assist in creating ability to strip NOAA data from forecasts and load into database – calibrate models based on actual data
   e. NNMC –
      i. capture and package pertinent data - separated for the individual steps depicted in the methodology,
      ii. correlate actual PV variability with NOAA % cloud cover forecast from day before,
      iii. perform optimization calculation for each test.
4. Assumptions
   a. Demonstration will isolate smoothing function of BESS system in order to demonstrate this smoothing function independently
   b. Test plan can be modified to accommodate shifting in later stages – 10 day window per subset assumes clouds will appear
   c. Irradiance sensors serve as baseline data, Primary kW serves as response to algorithm
   d. Increments of available BESS power capacity can be adjusted in order to demonstrate various output levels
   e. Demonstration period November 2011 to December 2014 will feature a wide variety of cloud types in each test period
   f. NOAA % cloud cover predictions are a good indicator of cloud types
   g. Feeder is stable and voltage stability from smoothing arises from mitigating ramp rates – this approach is translatable and applicable to high PV penetration feeders and will stabilize voltage in these situations
   h. Optimized regulation is based on ANSI Range A parameters
5. Constraints
   a. Not demonstrating on a high penetration feeder – results need to be translated via modeling
   b. Weather - Cloud types – demonstrations will need to correlate the % cloud cover with irradiance variation and cloud type is not a controlled variable
6. System Schematic
7. Use up to date system schematic for all demonstrations
8. Smoothing Algorithm - is revised iteration from SNL Memo 09 06 11
   a. Will be adjusted once per test period - current start version is __________

9. Equipment Requirements
    a. Points list alignment
        i. all Ion meters
        ii. field irradiance sensors
        iii. All met points
        iv. Data Acquisition System
        v. PI Data Base
        vi. Sharepoint portal
        vii. GridLAB
        viii. OpenDSS
    b. External data tags (data needed but not measured by DAQ)
        i. NOAA % cloud cover predictions
    c. 12.47kV Distribution System Configuration needs
        i. End of feeder
        ii. Beginning of feeder
10. Methodology
    a. Ensure BESS is receiving Primary Meter Voltage and kW, Irradiance values (averaged and sw sensor only)
    b. Ecoult keeps log of algorithm version and associated configurations within algorithm and associated dates of implementation
    c. Ecoult programs into BESS the increment of energy capacity for the dates and values in table below
    d. Capture data for the test period from PI, segregate for each test period and associate with NOAA predicted cloud cover data file for the dates of the test period
    e. Analyze each data set for each test period immediately after test period ends and assess the impact of smoothing for various battery capacities applied vs. mitigation of ramp rate –
        i. Assess test period data set – derive ramp rate from irradiance sensor change per second
        ii. Assess Primary meter kW for mitigation of ramp rate –
        iii. Graph irradiance sensor ramp rate vs primary meter ramp rate
        iv. Report data to PMO
    f. Demonstration of ACE signal following will be intermittent and targeted to later phases in the project
    g. Procedure – following table dictates parameters demonstrated and duration of each, if adequate

			Test Plan 1 Smoothing Control Source							
test label	period	Feeder Configuration	irradiance sensor	primary meter	PV Meter	ACE from PNM	Increment of Battery Capacity	Maximum Duration (days)	Start Date	End Date
1BPV0.1	**1**	B			**x**		10%	10	10/31/2011	11/10/2011
1BPV0.4	**1**	B			**x**		40%	10	11/16/2011	11/26/2011
1BPV0.7	**1**	B			**x**		70%	10	12/9/2011	12/28/2011
1BPV1	**1**	B			**x**		100%	10	1/3/2012	1/13/2012
2BP0.4	**2**	B	**averaged**				40%	20	1/19/2012	2/8/2012
2BP0.7	**2**	B	**averaged**				70%	15	2/14/2012	2/29/2012
2BP1	**2**	B	**averaged**				100%	18	3/6/2012	3/24/2012
3BIRRA0.4	**3**	B	**sw corner**				40%	15	3/30/2012	4/14/2012
3BIRRA0.7	**3**	B	**sw corner**				70%	15	4/20/2012	5/5/2012
3BIRRA1	**3**	B	**sw corner**				100%	10	5/14/2012	5/24/2012
4BPV0.6	**4**	B			**x**		60%	10	5/30/2012	6/9/2012
4BPV0.8	**4**	B			**x**		80%	10	6/15/2012	6/25/2012
4BPV1	**4**	B			**x**		100%	10	7/1/2012	7/11/2012
5BPV0.6	**5**	B			**x**		60%	10	7/17/2012	7/27/2012
5BPV0.8	**5**	B			**x**		80%	10	8/2/2012	8/12/2012
5BPV1	**5**	B			**x**		100%	10	8/18/2012	8/28/2012
6BPV0.6	**6**	B			**x**		60%	10	9/3/2012	9/13/2012
6BPV0.8	**6**	B			**x**		80%	10	9/19/2012	9/29/2012
6BPV1	**6**	B			**x**		100%	10	10/5/2012	10/15/2012
7BPV0.6	**7**	B			**x**		60%	10	10/21/2012	10/31/2012
7BPV0.8	**7**	B			**x**		80%	10	11/6/2012	11/16/2012
7BPV1	**7**	B			**x**		100%	10	11/22/2012	12/2/2012
8BPV0.6	**8**	B			**x**		60%	10	12/8/2012	12/18/2012
8BPV0.8	**8**	B			**x**		80%	10	12/24/2012	1/3/2013
8BPV1	**8**	B			**x**		100%	10	1/9/2013	1/19/2013
9EBEST0.6	**9**	B	**Best**	**Best**	**Best**		60%	5	1/25/2013	1/30/2013
9EBEST0.8	**9**	B	**Best**	**Best**	**Best**		80%	5	2/5/2013	2/10/2013
9EBEST1	**9**	B	**Best**	**Best**	**Best**		100%	5	2/16/2013	2/21/2013
10EBEST0.6	**10**	B	**Best**	**Best**	**Best**		60%	5	2/27/2013	3/4/2013
10EBEST0.8	**10**	B	**Best**	**Best**	**Best**		80%	5	3/10/2013	3/15/2013
10EBEST1	**10**	B	**Best**	**Best**	**Best**		100%	5	3/21/2013	3/26/2013
11EBEST0.6	**11**	B	**Best**	**Best**	**Best**		60%	10	4/1/2013	4/11/2013
11EBEST0.8	**11**	B	**Best**	**Best**	**Best**		80%	10	4/17/2013	4/27/2013
11EBEST1	**11**	B	**Best**	**Best**	**Best**		100%	10	5/3/2013	5/13/2013
12EBEST0.6	**12**	B	**Best**	**Best**	**Best**		60%	10	5/19/2013	5/29/2013
12EBEST0.8	**12**	B	**Best**	**Best**	**Best**		80%	10	6/4/2013	6/14/2013
12EBEST1	**12**	B	**Best**	**Best**	**Best**		100%	10	6/20/2013	6/30/2013
13EBEST0.6	**13**	B	**Best**	**Best**	**Best**		60%	10	7/6/2013	7/16/2013
13EBEST0.8	**13**	B	**Best**	**Best**	**Best**		80%	10	7/22/2013	8/1/2013
13EBEST1	**13**	B	**Best**	**Best**	**Best**		100%	10	8/7/2013	8/17/2013
14EBEST0.6	**14**	E	**Best**	**Best**	**Best**		60%	10	8/23/2013	9/2/2013
14EBest0.8	**14**	E				**x**	80%	15	9/8/2013	9/23/2013
14EBest1	**14**	E				**x**	100%	15	9/29/2013	10/14/2013
15BBest0.6	**15**	B				**x**	60%	15	10/20/2013	11/4/2013
15BBest0.8	**15**	B				**x**	80%	15	11/10/2013	11/25/2013
15BBest1	**15**	B				**x**	100%	15	12/1/2013	12/16/2013

7/16/2012

a. For each test measure – all available in PI database
   i. PV Irradiance (all 6 points and average)

ii. Primary meter Volts
iii. Primary meter kW
iv. PV meter Volts
v. PV meter kW
vi. Battery Meter kW
vii. Associated cloud prediction (via NOAA predicted % cloud cover)

11. Deliverables
    a. For each subset period set (labeled test label) an analysis of ramp rate (change in output) derived from irradiance sensor average vs. associated ramp rates on primary meter kW – graphed for each day in test period with associated data set in excel file (NNMC) – 1 second intervals
    b. For each subset period a correlation analysis of NOAA predicted % cloud cover for a given day vs. actual irradiance average (NNMC)
    c. For each subset period in above table an optimization analysis graph showing the ramp rate mitigation for each configuration in the test plan (NNMC)
    d. For the overall test plan (excluding ACE input) an optimization analysis graph showing the ramp rate mitigation for all configurations tested (NNMC)
12. Reports
    a. Correlation analysis between NOAA cloud cover prediction and actual irradiance (NNMC)
    b. Optimization analysis for each subset (test label) (NNMC)
    c. Optimization analysis for overall test plan (NNMC)
    d. Overall test report for incorporation into DOE TPR periodically 12/11, 6/12/, 12/12, 6/13, 12/13,6/14, 12/14 (PNM)
    e. Inclusion of above reports in DOE Final Report (PNM)

8.2.2 PNM/DOE Test Plan 2 - Firming of PV

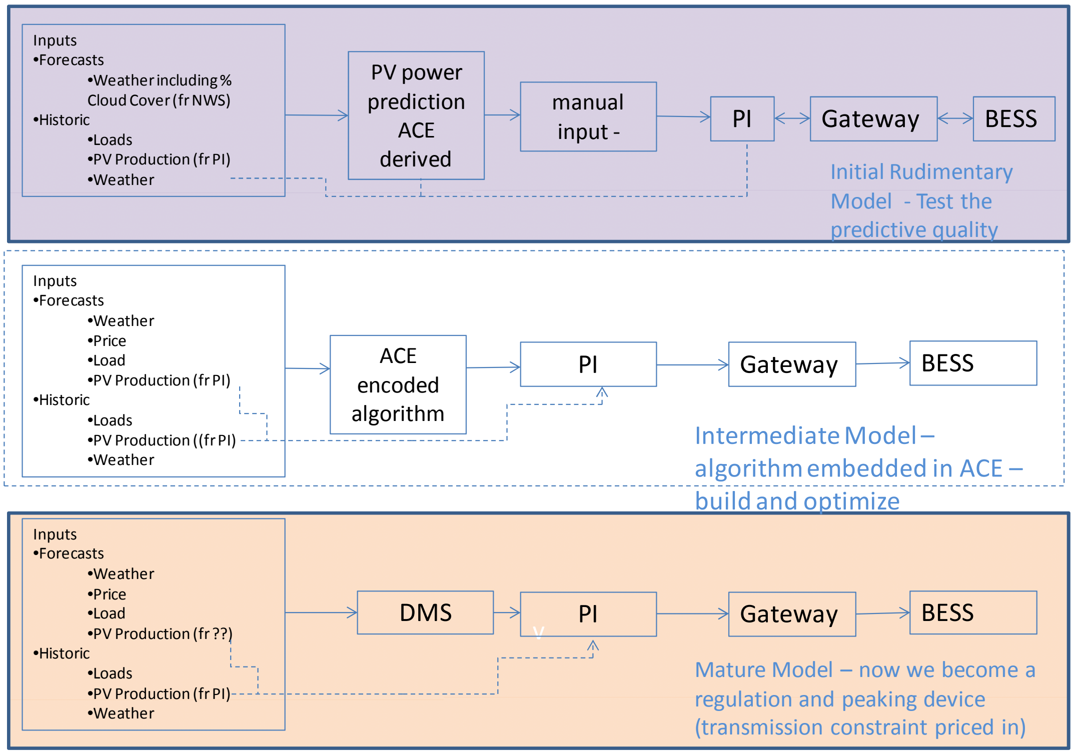
Revision History

Date	Version	Description	Author
3/29/11	1.0	Initial draft	Steve Willard
03/27/12	2.0	Revision to schedule and details on algorithm implementation	Steve Willard
04/30/12	3.0	Revision to schedule and procedure	Steve Willard
07/02/12	3.2	Addition of target shapes	Steve Willard

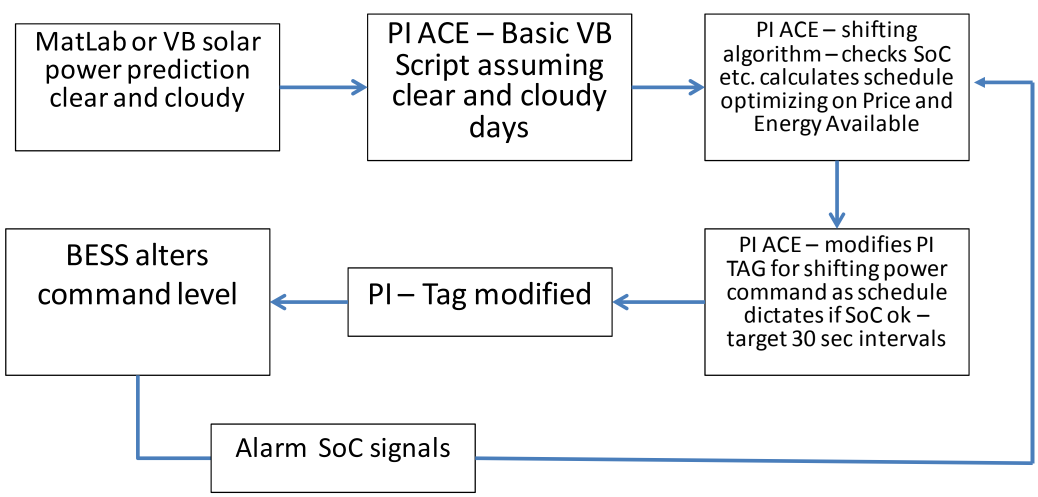
1. Objectives
    a. Primary – demonstrate Battery/PV integrated system meets PNM definition of "firm/dispatchable resource"
    b. Secondary
        i. Develop and implement a progressively sophisticated algorithm that is driven by an increasing number of variables
            1. PV forecast
            2. Load forecast
            3. Price Forecast
            4. Feedback from near real time operation
            5. Interaction with smoothing battery
        ii. validate field base algorithm with UNM models
        iii. validate UNM models with field data
2. Scope/Requirements
    a. In Scope – shifting portion of East Penn batteries, DMS or prototype thereof
    b. Out of Scope – peak shaving
3. Roles & Responsibilities
    a. Ecoult/East Penn – support battery system
    b. PNM – lead, algorithm development, source of signal to BESS
    c. Sandia - monitor
    d. UNM – models, algorithm development
    e. NNMC – optimization, package data – separated for the individual steps depicted in the methodology
4. Assumptions –
    a. PNM sends power signal from prototype DMS (PI ACE) which has embedded algorithm
    b. DMS is connected 24/7
    c. Firming is based on PNM system needs – not distribution (Peak Shaving)
        i. Price
        ii. Weather

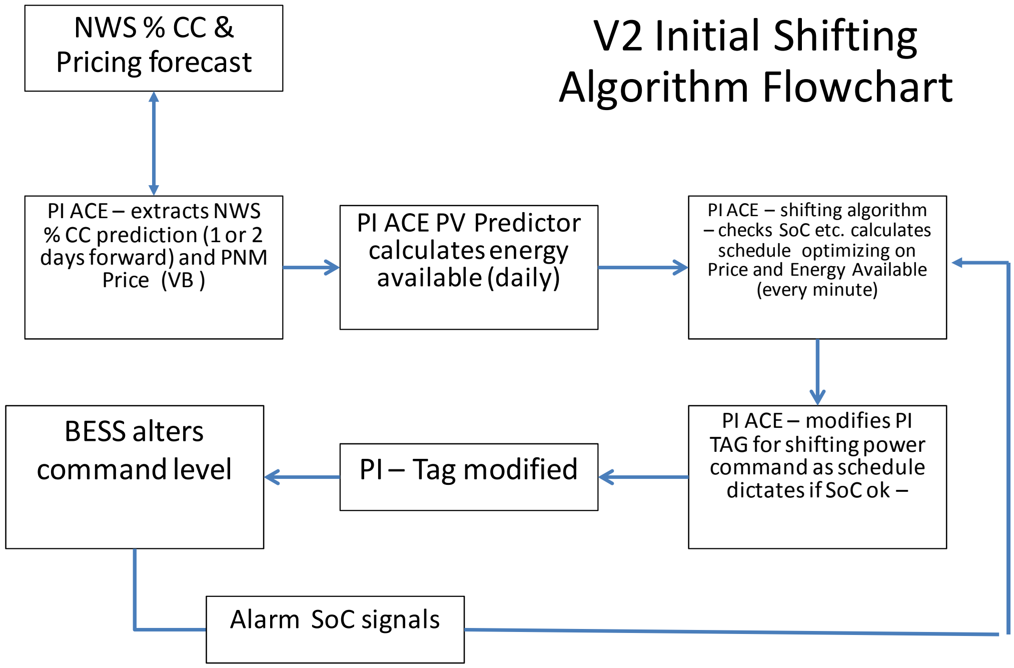
  iii. Load forecast
  iv. PV forecasts
5. Constraints –
   a. data sources are clear for price, weather and PV production forecast is accurate
   b. Smoothing needs to accommodate shifting in order to keep flat top
6. Process flow – evolution of algorithm development and system integration

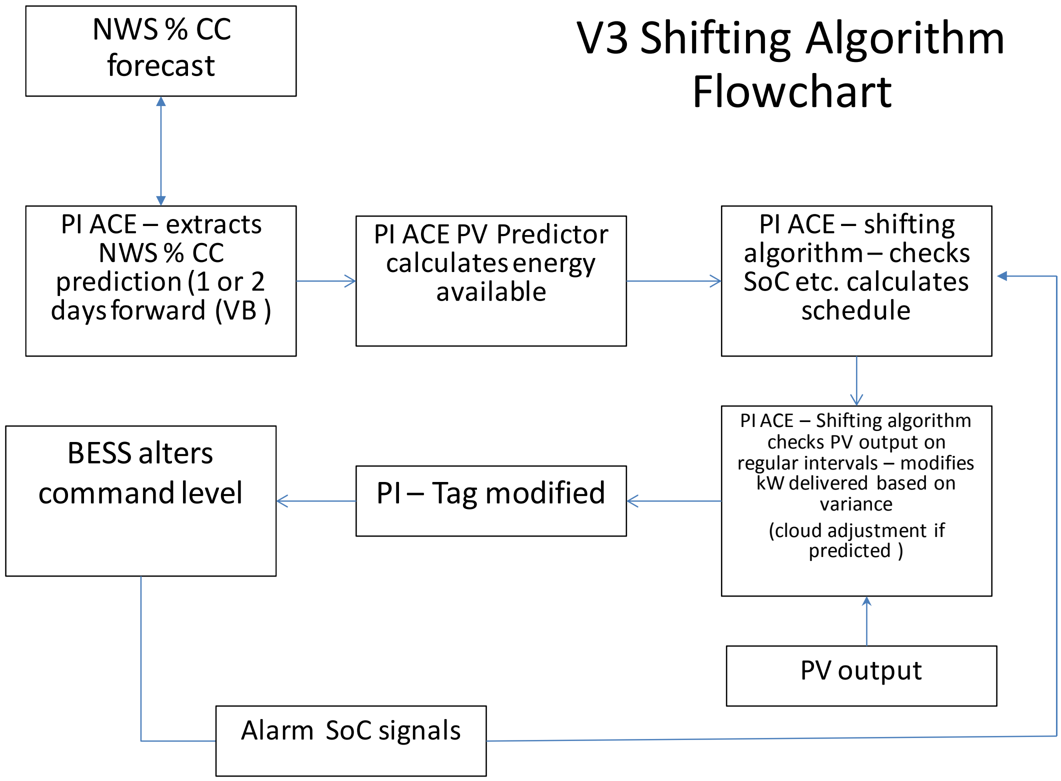
Shifting Algorithm - Development Process Flow



V1 Initial Shifting Algorithm Flowchart



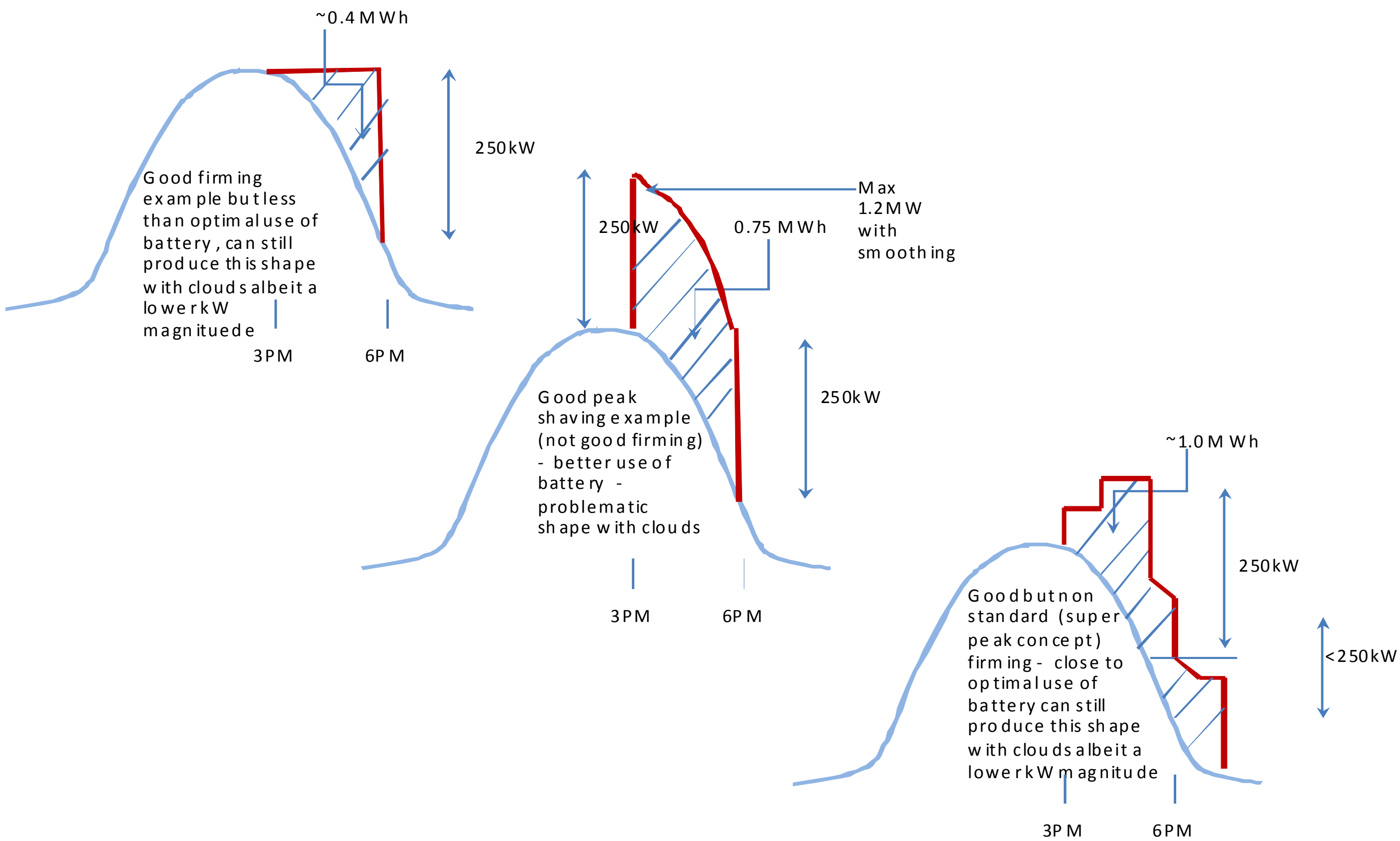

V2 Initial Shifting Algorithm Flowchart
NWS % CC & Pricing forecast
PI ACE – extracts NWS % CC prediction (1 or 2 days forward) and PNM Price (VB)
PI ACE PV Predictor calculates energy available (daily)
PI ACE – shifting algorithm – checks SoC etc. calculates schedule optimizing on Price and Energy Available (every minute)
PI ACE – modifies PI TAG for shifting power command as schedule dictates if SoC ok –
PI – Tag modified
BESS alters command level
Alarm SoC signals



7. Development Steps in Algorithm - following Optimizations are required
    a. Hardware based –
        i. Time constants
        ii. Dead-bands
        iii. Amplitudes
    b. Algorithm based - including interaction of smoothing algorithm with shifting
    c. Methodology based
    d. Weather based

8. Equipment Requirements
    a. Points list alignment (which points are needed?)
        i. PI registers to instruct BESS
        ii. PV output kW
        iii. BESS SOC (shifting)
        iv. Primary meter kW
        v. PV REC meter
    b. External data tags (data needed but not measured by DAQ)
        i. Plant proxy emissions
            1. Gas

        ii. plant LCOE
            1. Gas
            2. Cloud cover prediction
            3. Historic PV (from PI)
            4. Load forecast
            5. Other weather (wind, temp) forecasts
    c. System Configuration needs
        i. End or beginning of feeder
9. Methodology
    a. Simple to complicated development
        i. Start with only PV forecast simple version – manual operation
        ii. Move to automated operation slowly with following of change of schedule increments from PI ACE (routines with different increments to be loaded individually
            1. 1 minute – 4 -10 day duration
            2. UNM based algorithm – clear day only evening production (after PV drops below 75kW)
            3. 1 minute with block schedules (start/stop at a specific time)
            4. 1 minute Block schedules with cloudy day
            5. 1 minute with block schedules with auto strip of % cloud cover forecast
            6. 30 seconds – remainder of test



iii. Test different shapes outputs

iv. Next implement load forecast
v. Short Term Software versioning plan

b. Timeline
   i. Seasonality effects –
      1. Winter – 2 peaks
         a. Morning – less important
         b. Evening – more important
         c. Dec-Feb: HE6-9 & HE18-21

      2. Shoulder – 2 peaks
         a. Nov: HE5-8 & HE18-21
         b. Mar: HE5-8 & HE18-21
      3. Summer - 1 peak
         a. April-October HE14-20 (6 hour)

c. Test Plan Schedule

Detailed Versioning Plan - Short Term V3.2								
Version ID	Description	PV Forecast	Schedule Change Increment	Duration (days	Summer or Winter	Start Date	End Date	Actual Start
0.1	Manual adjusmtemt through gateway	clear and cloudy	15 minute	1	W	2/28/112	2/28/2012	2/28/2012
0.2	Manual adjusmtemt through gateway	clear	5 minute	1	W	3/21/2012	3/21/2012	3/21/2012
1.3	Automated in PI ACE at PNM no forecast	clear	1 minute	4	S	4/27/2012	5/1/2012	4/30/2012
1.4	Automated in PI ACE at PNM no forecast - clear sets used (No Cloudy)	clear	1 minute	4	S	5/2/2012	5/6/2012	5/1/2012
2.01	Automated in PI ACE at PNM no forecast - clear sets used (No Cloudy)	file based	1 minute	10	S	5/7/2012	5/17/2012	5/8/2012
2.0	Automated in PI ACE at PNM - version B of predictive engine with NWS prediction	file based	1 minute	30	S	5/18/2012	6/17/2012	6/11/2012
2.03	Automated in PI ACE at PNM - version B of predictive engine	file based	30 seconds	5		6/18/2012	7/31/2012	8/6/2012
2.1	Automated in PI ACE at PNM - version B of predictive engine	auto derived %CC	1 second	30		8/7/2012	9/6/2012	
	Utilizing super peak shape instead of rectangle	auto derived %CC	1 second	50		9/7/2012	10/27/2012	
3.0	back to winter schedule with super peak for now	new sources	1 second	70		10/28/2012	1/6/2013	
3.5	revised winter with super peak and ICE PV prices	new sources	1 second	70		1/7/2013	3/18/2013	
4.0	Revised to include arbitrage	new sources	1 second	30		3/23/2013	4/22/2013	
5.0	Revised to include load forecast proto DMS	new sources	1 second	40		4/23/2013	6/2/2013	
6.0	DMS Revised to optimize battery life and maximum economic incentive	new sources	1 second	150		6/3/2013	10/31/2013	

10. Deliverables
    a. Test Plan
    b. Test Schedule
    c. Test Specifications
    d. Requirements Traceability Matrix
11. Reports

a. Interim – Align TPRs for DOE
b. Final with sign off Cloud types

8.2.3 PNM/DOE Test Plan 3 - Arbitrage

Date 4/4/2011

Version 1.0

13. Objectives
    a. Primary – demonstrate DMS system can effectively send charge and discharge commands to battery system based on market inputs
    b. Secondary –
        i. Establish system efficiency at various levels
        ii. Establish higher value RECs from PV - Based on coal emissions
14. Scope/Requirements
    a. In Scope – shifting portion of East Penn batteries, DMS
    b. Out of Scope - smoothing portion of East Penn batteries, PV maybe
15. Roles & Responsibilities
    a. Ecoult/East Penn – support battery system
    b. PNM – lead, algorithm development, source of signal to BESS
    c. Sandia - monitor
    d. UNM - models
    e. NNMC – package data - separated for the individual steps depicted in the methodology
16. Assumptions –
    a. PNM sends power signal from prototype DMS which has embedded algorithm
    b. DMS is connected 24/7
    c. Source of price tables is both historical and forecast
        i. Price
        ii. Weather
        iii. Load forecast
17. Constraints – data sources are not clear for price, weather
18. System Schematic
19. Equipment Requirements
    a. Points list alignment (which points are needed?)
    b. External data tags (data needed but not measured by DAQ)
        i. Plant proxy emissions
            1. Coal
            2. Gas
        ii. plant LCOE
            1. Wind
            2. Coal
            3. Gas
    c. System Configuration needs
        i. End/beginning of feeder doesn't matter

20. Methodology
    a. Timeline
        i. Seasonality effects
    b. Procedure – how who when

Dispatch Source

test label	period	Price Table	Price Lookback	Price Forecast	size increment	duration
3AT0.55	1	x			55%	2
3AT0.65	1	x			65%	2
3AT0.75	1	x			75%	2
3AT0.85	1	x			85%	2
3AT0.95	1	x			95%	2
3AL0.55	2		x		55%	2
3AL0.65	2		x		65%	2
3AL0.75	2		x		75%	2
3AL0.85	2		x		85%	2
3AL0.95	2		x		95%	2
3AF0.55	3			x	55%	2
3AF0.65	3			x	65%	2
3AF0.75	3			x	75%	2
3AF0.85	3			x	85%	2
3AF0.95	3			x	95%	2

    c. Problem recording and data recording
21. Deliverables
    a. Test Plan
    b. Test Schedule
    c. Test Specifications
    d. Requirements Traceability Matrix
22. Reports

   a. Interim – Align TPRs for DOE
   b. Final with sign off Cloud types

8.2.4 PNM/DOE Test Plan 4 – Peak Shaving

Date

Version 0

23. Objectives
    a. Primary – demonstrate Battery/PV integrated system can defer in high penetration of PV feeder
    b. Secondary
       i. Establish system efficiency at various levels
       ii. Determine the optimum battery size balancing efficiency for maximum deferral contribution
       iii. validate UNM models – also extract impacts of high pv on LTC cap banks
24. Scope/Requirements
    a. In Scope – shifting portion of East Penn batteries, DMS
    b. Out of Scope - smoothing portion of East Penn batteries
25. Roles & Responsibilities
    a. Ecoult/East Penn – support battery system
    b. PNM – lead, algorithm development, source of signal to BESS
    c. Sandia - monitor
    d. UNM - models
    e. NNMC – package data - separated for the individual steps depicted in the methodology
26. Assumptions –
    a. PNM sends power signal from prototype DMS which has embedded algorithm
    b. DMS is connected 24/7
    c. Application is applied by proxy to high penetration feeder
    d. Peak Shaving is based on distribution feeder needs not PNM system (firming)
       i. Price
       ii. Weather
       iii. Load forecast
27. Constraints – data sources are clear for price, weather
28. System Schematic
29. Equipment Requirements
    a. Points list alignment (which points are needed?)
    b. External data tags (data needed but not measured by DAQ)
       i. LTC/Cap erosion by PV data
       ii. Load growth for deferral of upgrade
    c. System Configuration needs
       i. End of feeder

ii. Beginning of feeder

30. Methodology
   a. Timeline
      i. Seasonality effects
   b. Procedure – how who when

Dispatch Source

test label	period	Load History	Weather Forecast	Load Forecast	size increment	duration
42PH0.55	1	x			55%	5
42PH0.65	1	x			65%	5
42PH0.75	1	x			75%	5
42PH0.85	1	x			85%	5
42PH0.95	1	x			95%	5
4PFW0.55	2		x		55%	5
4PFW0.65	2		x		65%	5
4PFW0.75	2		x		75%	5
4PFW0.85	2		x		85%	5
4PFW0.95	2		x		95%	5
4PFL0.55	3			x	55%	5
4PFL0.65	3			x	65%	5
4PFL0.75	3			x	75%	5
4PFL0.85	3			x	85%	5
4PFL0.95	3			x	95%	5

   c. Problem recording and data recording

31. Deliverables
   a. Test Plan
   b. Test Schedule
   c. Test Specifications
   d. Requirements Traceability Matrix

32. Reports
   a. Interim – Align TPRs for DOE
   b. Final with sign off Cloud types

8.2.5 PNM/DOE Test Plan 5 – Optimized Operation

Date April 4, 2011

Version 1.0

33. Objectives
    a. Primary – demonstrate Battery system can simultaneously shift and smooth PV output Secondary –
        i. Establish system efficiency at various levels
        ii. Simultaneously perform arbitrage duty while pursuing primary goal
34. Scope/Requirements
    a. In Scope – shifting portion of East Penn batteries, DMS
    b. Out of Scope - smoothing portion of East Penn batteries, PV maybe
35. Roles & Responsibilities
    a. Ecoult/East Penn – support battery system
    b. PNM – lead, algorithm development, source of signal to BESS
    c. Sandia - monitor
    d. UNM - models
    e. NNMC – package data - separated for the individual steps depicted in the methodology
36. Assumptions –
    a. PNM sends power signal from prototype DMS which has embedded algorithm
    b. DMS is connected 24/7
    c. Source of price tables is both historical and forecast
        i. Price
        ii. Weather
        iii. Load forecast
37. Constraints – data sources are clear for price, weather
38. System Schematic
39. Equipment Requirements
    a. Points list alignment (which points are needed?)
    b. External data tags (data needed but not measured by DAQ)
        i. Plant proxy emissions
            1. Coal
            2. Gas
        ii. plant LCOE
            1. Wind
            2. Coal
            3. Gas
    c. System Configuration needs
        i. End of Feeder
        ii. Beginning of feeder

40. Methodology
    a. Timeline
        i. Seasonality effects
    b. Procedure – how who when
    c.

Test	Duration	Start	End
Smoothing + Peak Shaving	40 days	12/14/2012	2/7/2013
Smoothing + Arbitrage	40 days	2/8/2013	4/4/2013
Smoothing + Firming	40 days	4/5/2013	5/30/2013
Smoothing + Firming + Arbitrage	60 days	5/31/2013	8/22/2013
Optimized Combination	30 days	8/23/2013	10/3/2013

    d. Problem recording and data recording
41. Deliverables
    a. Test Plan
    b. Test Schedule
    c. Test Specifications
    d. Requirements Traceability Matrix
42. Reports
    a. Interim – Align TPRs for DOE
    b. Final with sign off Cloud types