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Analysis with Smart Grid Methods & Solutions

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ANALYSIS WITH SMART GRID METHODS & SOLUTIONS

by

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THESIS

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ABSTRACT

Smart Grid Technologies such as demand Response, energy storage, microgrids, advanced communication technologies, and are being rapidly adopted into the electric grid by the each technology. Utilities making efforts to support, invest, adopt and implement these. One challenge is not necessarily adopting the technology, but first identifying the impact of the technology and comparing with its benefits. Another challenge, and the most important one, is how would all these technologies work together on the electric grid. One benefit of a technology might be counterproductive to a benefit from another technology. This challenge of understanding multiple technologies is important because when analyzing the methods and solutions of one, may introduce other parameters that could counter another technologies benefit. Universities, Research institutes, and utilities are working together to understand how all these technologies work together and identifying how to maximize the benefit to both customers and the utility grid with minimal impacts to the grid.

The purpose of this thesis is to identify technologies and understand each of its characteristics to associate each other in respect to methods of grid operations. This thesis will address how these technologies work together in an automated way through various communications to improve efficiencies, reliability, and sustainability of the electric grid.

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1. Introduction

Smart Grid Technologies such as demand Response, energy storage, microgrids, advanced communication technologies, and are being rapidly adopted into the electric grid for the obvious benefits presented by the each technology. Utilities have to re-invent themselves to support, invest, adopt and implement these. One challenge is not necessarily adopting the technology, but first identifying the impact of the technology and comparing it with its benefits. Another challenge, and the most important one, is how would all these technologies work together on the electric grid. One benefit of a technology might be counterproductive to a benefit from another technology. This challenge of understanding multiple technologies is important because when analyzing the methods and solutions of one, may introduce other parameters that could counter another technologies benefit. Most of these technologies have not yet met the maturity of productivity in the industry. This means it is more important to learn about each technology not only to recognize the societal benefit, but understand how multiple technologies work together. Universities, Research institutes, and utilities are working together to understand how all these technologies work together and identifying how to maximize the benefit to both customers and the utility grid with minimal impacts to the grid.

In order to complement the methods mentioned above, analysis and technologies presented so far, a converter that would take the utility's GIS data to an application designed to do smart grid analysis is needed. Having this in place will introduce value with demonstrations as well as show visibility to areas that are not known today. One use case for an example would be understanding penetrations levels of PV. With penetration levels of distributed generation increasing, especially solar photovoltaic (PV), the need is growing to have tools that accurately analyze the impacts of allowing such resources on our utility grid. Existing analytical tools in many utilities (including PNM) are limited in their ability to capture the real-time behavior of distributed solar PV systems. Without advanced technologies such as advanced metering infrastructure (AMI), dynamic modeling provides the best approach to understanding the impacts of distributed generation on a utility's system. The Electric Power Research Institute (EPRI) developed a software tool called OpenDSS [1] that allows this type of enhanced modeling, by providing second-by-second impacts to a distribution system in a given scenario.

2. Goals & Purpose

The purpose of this thesis is to identify technologies and understand each of its characteristics to associate each other in respect to methods of grid operations. This thesis will address how these technologies work together in an automated way through various communications to improve efficiencies, reliability, and sustainability of the electric grid.

There are many different concepts being presented and tested to implement these goals around ways to improve efficiencies, reliability, and sustainability of the electric grid. Most technologies present complex systems present multiple parameters that need to be considered for operations of the electric grid. Select systems will be defined and outlined in this thesis. Also, they are different in each geographic area, customer type (load behavior), demand, and geometry of each circuit on every system. To represent this complexity and possible solutions, this paper will use demonstrations of micro grids, Electric Vehicles, and Energy storage to present methods of complex control of smart grid modeling and operational methods.

3. Methodology for Analysis

3.1. Analysis tools and data

Utilities have software applications that utilize GIS data (Geographic Information System) to perform different types of analysis. GIS data is the repository of the electric grid assets in a spatial format. And furthermore, the GIS acts like a platform of electric grid data that any software application can pull from and perform its analysis. Software or applications not only need electric grid data but is necessary to have real data with minimal data gaps or errors. The frequency of data like utility load data and Distributed generation (customer and utility grid scale) needs to be one second or one minute. In some cases even sub-second intervals to capture reliability impacts of new installations of distributed generation as well as new technology implementations. An example is represented in figure 1.

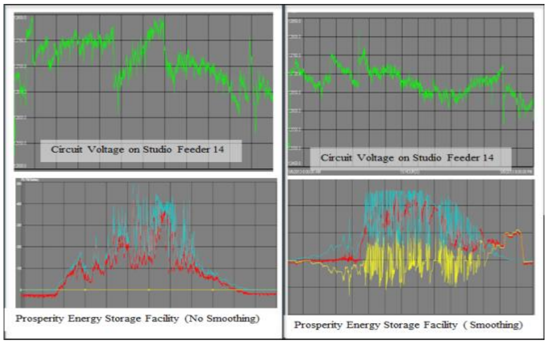

Figure 1 Green is sub-second data @ 30 samples per second representing the voltage fluctuations on a utility distribution circuit caused by clouds.

Many utilities have communication systems that are only 15 minute data. In order to perform accurate analysis, granular data is necessary to accurately perform an analysis. Historically, the applications used in utilities use a method of a snap shot in time. For example to understand what a grid scale solar plant will do when a utility plans to build a 5MW solar facility, sometimes the only data available is maximum load and minimal load. These two parameters are used to cover the range of possible load values to understand the impacts of installing a large solar facility. However, as mentioned above, we need to close the gap by using a time varying method and granular data. So, instead of two parameters that are a snapshot in time, we would use second by second analysis.

This time varying method also is important when understanding reliability impacts due to increasing solar penetration on the electric grid.   Typically, one would utilize data that is sampled at 15 minutes. There are events that can only be captured when doing analysis within the 15 minutes. For example a load tap change (LTC) at the substation transformer can happen in seconds to adjust to the voltage level (This is called voltage mitigation). This is described in figure 1. In order to simulate these LTC operations, time varying and granular data is needed.   This method of utilizing the correct data, data format, and accurate granular data is the baseline to supporting multiple analyses on different smart grid technologies on the electric grid.

3.2. Utilizing the correct data

Utilizing the correct data requires extensive knowledge and experience in the utility grid operations. Example is the experience the Distribution Planning and development business unit in an electric utility.   As mentioned before, GIS data is extremely important in performing analysis. Being able to utilize advanced modeling tools/applications, one needs access or exact GIS information reflecting a utility circuit that is part of the electric grid.

Software and applications must have the ability to perform time varying analysis. One application that does this well is EPRI's (Electric Power Research Institute) OpenDSS application[1] OpenDSS is an open source electric power Distribution System Simulator (DSS). It supports multiple technologies described in this paper and also supports all distributed resources integration and grid modernization efforts.

In the applications and demonstrations in this paper, we will be utilizing OpenDSS. However, circuits from a utility need to be made available in OpenDSS format. Taking the latest source file from a utility's GIS data base and reading it into a code based converter to create a circuit set in OpenDSS format is a crucial tool. An average utility may have over 1000 circuits in their service territory.   Having a converter in place will expand the opportunity base to do analysis based on what type of analysis may be needed. Examples of these types of analysis are high PV penetration impacts, time varying load shifting with a new technology such as EV, reliability, and economical benefit of the invested technology.

3.3. Modeling methods

As mentioned above, the methods feed into a framework for analysis that may be different for each technology. The framework defined needs to accommodate all parameters and considerations in order to understand how multiple technologies work together.

Steady state analysis is used to accommodate parameters such as maximum loads. This method determines worse case scenarios for each scenario or test plan defined. Test plans are a set of baseline metric to measure the analysis results against. Circuit monitors are inserted into the targeted areas of the circuit to measure the results to understand any violations such as defined in voltage control. This is important because it takes into account circuit characteristics. Given there are thousands of circuits to consider, all characteristics need to be considered. It is important to define all characteristics of each technology find correlations of characteristics of other technologies. This method will take into consideration multiple technologies when trying to identify impacts and benefits of multiple technologies on an electric grid.

Determining these benefits through carefully planned methods to support the framework develop criteria such as voltage, loading, protection, and power quality. These methods will support modernization efforts to add more solar (I.E hosting capacity)

4. Smart Grid Analysis and methods

4.1. GIS data Converter

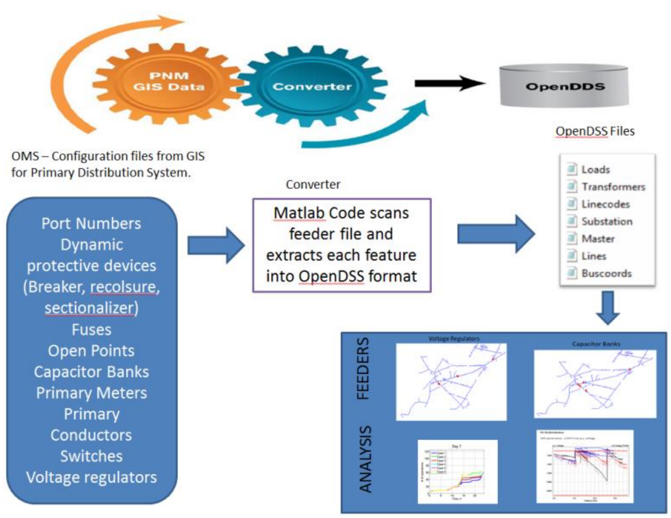

Figure 2 Flow chart of the OpenDSS Converter

The GIS data Converter takes individual files based on a configuration file that is set up for an OMS model and converts them into an OpenDSS format. The contents include features such as busbar, dynamic protective device (breaker, recloser, sectionalizer), fuse, open point, cap banks, primary meters, primary conductor (OH and UG), switch, transformer, and voltage regulator. The files are based on the OMS (Outage management System) extract. These files are the same files that Synergee®Electric uses for modeling functions in distribution planning. The advantage here is there is a one for one comparison for R&D development along with stand modeling practices in the utility.

Benefits and results

Once OpenDSS has converted data from the utility, monthly customer usage data, statistics related to typical daily customer usage, and information from customer PV interconnections are input to create detailed models within OpenDSS. Analysis can now be performed on a selection of the multiple circuits with certain parameters to identifying impacts at a minute-by-minute or hour-by-hour timeline. Analysis also can be performed on circuits to simulate other emerging technologies, such as battery storage.

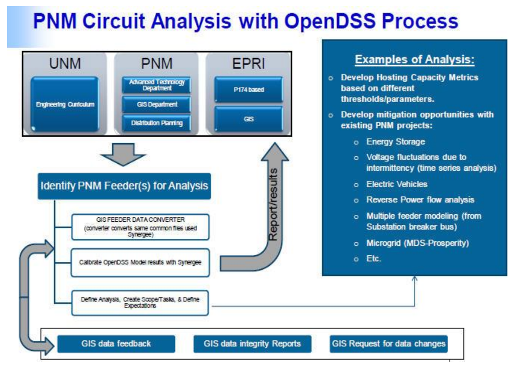

Figure 3 Method and process adopted by PNM

By using OpenDSS modeling to optimize control algorithms will help characterize feeders to understand where on the utility grid smart grid technology (like energy Storage) and high levels of distributed generation can be of greatest value. Developing the OpenDSS Converter resulted in ability of all PNM utility circuits being modeled. Example of the process to capture value, implementation and provide feedback into R&D.

4.2. Electric Vehicles and Analysis

Electric Vehicles (EV) have the potential to significantly impact local electrical demand and usage. This potential impact can be exacerbated by the fact that initial EV adoption profiles will not be evenly distributed across local electrical distribution networks also known as “clustering”. Considering the power requirements of a single EV is equivalent to that of a small home, even low EV penetration can have deleterious effects on secondary service transformers. Initial EV adoption is projected to be heavily dependent on household demographics such as income, educational attainment and household ownership. A study and analysis was performed to understand these impacts and identify opportunities for mitigation. Also the opportunities will be used to work with other technologies later in this paper.

The first step to understanding this technology is to complete an assessment of EV penetration and model with other DER to develop an accurate system model to take in account multiple energy sources to provide a granular understanding of the impacts and performance of a distribution grid. This effort is to describe a methodology and approach developed to optimize scenarios for grid operators and the utilities distribution planning. Understanding the impacts on distribution systems operation requires understanding of EV load variations as well as network location. Traditional methods of load planning will not be possible due to spatial uncertainty in EV distribution, charging patterns and individuality of the new loads. The complexity of the EV penetration along with other DERs will be demonstrated in this paper through different modeling tools such as OpenDSS (EPRI), GridLab-D (PNNL) [2], and Synergee®Electric [3].

The test area is located in PNM's urban area is located in Albuquerque, New Mexico. Albuquerque consists of approximately 75 Distribution Substations and 300 feeders. Each Feeder provides power to 1500 customers on average. Utilizing The American Community Survey (ACS), at the Tract Level, and Weighted Factor Analysis, a EV Adoption Propensity Score was determined for each ACS tract. The resulting scores were used to identify which residential areas are more likely to adopt Electric Vehicles. Electric vehicle manufacturers use adoption of non-plug in hybrid vehicles as an early indicator of the market segment that would be likely to adopt a plug in version. As part of this project, correlation was done to current Hybrid owners in New Mexico. This was determined by using the Motor Vehicle registration data to correlate EV Adoption Propensity Score results. The results are six feeders and which this project will use to perform analysis. The long term approach and visibility of EV penetration from a substation level and the impacts will be studied from a feeder loading perspective. A short term approach to modeling and visibility of EV Penetration will be done at the transformer level.

Figure 5: Demographic results of 6 circuits in the NE area of Albuquerque, New Mexico.

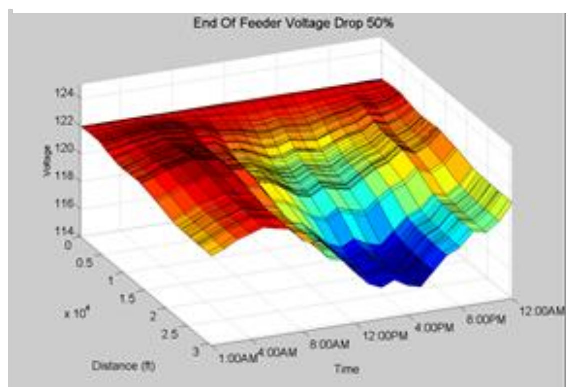

Figure 4 shows voltage profile along the feeder length for 5 of the test cases above, for 2%, 5%, 10%, 20% and 50% EV penetration levels, with EVs clustered toward the end of the feeder.

Using PNMs internal modeling software Synergee®Electric, a study was performed for single phase load vs commercial load to separate Volt-Var and motor start loads on the feeder from a modeling perspective. Analysis targeted a variety of parameters such as: Three to four models that project a 1-2 year penetration, 2-5 year penetration, and a 5-10 year penetration. This test plan methodology will support the short term analysis as well as long term. The penetration levels will follow a 10-20% increment of EV penetration between each model. By building 24 baseline models for each penetration level for every hour of the day has enable a time varying model that will use parameters such as charge times and correlate them with PNMs system peak load on a feeder basis. These mature models with high penetration of EV will support and integration with other smart grid technologies.

Voltage levels throughout the feeder distance need to meet ANSI -A standards with a 6V voltage drop or 5% change. Figure 3 illustrates that, although for the modeled scenarios in our test cases, voltages are still within the ANSI C84.1 [4] standard specification, the 50% EV penetration case does not leave a lot of margin for any other potential events to be mitigated.

Now we are able to target some of these impacts with mitigation opportunities. Three main strategies were assigned to each general assumption from the analysis above. Vehicle to Grid (V2G), Demand Response and Smart Charging.

> **Vehicle to Grid** is a system to when electric vehicles can be defined as a service to the power grid through communication to target demand response and other ways to deliver services to the grid.
> **Demand Response** is any changes in power usage by customers. These changes could be pricing from the utility to change energy consumptions over time.
> **Smart Charging** is a method to utilize technology that allows a battery to be charged and recharge based on input from status of battery and electric grid parameters such as time of charge/discharge.

Demand Response using EV can be a benefit to the utility and customer consumption from the grid by reducing their consumption at critical or peak times. FERC Definition Changes in electric use by demand-side resources from their normal consumption patterns in response to changes in the price of electricity, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized. A recent study funded by the Department of Energy shows 1.3-1.8kW can be saved per customer by a demand response application. By utilizing technology and applications such as TOU and DR, 1.7MW (note: 1888 customers on feeder analyzed) can be mitigated to non-peak times of day and/or areas. This is almost half of a typical feeder capacity and could result in capital savings towards the cost of a peaking resource such as a $5-6M substation. V2G can also inherit the mitigation opportunities through a demand response program in respect to discharging. So far, electric vehicle adoption is only focused on how to connect the vehicles to the grid, which from a utility perspective is an issue in itself in both short and long term capacity. V2G technology will be added to the mature models to study the aggregation of the storage capability and how electric vehicles could provide support to the grid. Although still in conceptual stage in the industry, NIST established a working group for V2G to develop interconnection standards at a national level in 2011. This is an opportunity to connect to a grid operator through a demand response program. Vision is to have EV discharge to supply the customer load or possibly even have the power flow back to the grid when plugged into a charging station. In aggregate, V2G is an opportunity for use as an energy storage resource. The impact analysis will identify the predictable patterns for an aggregate of Energy stored to be used by the utility. An aggregate of residential EV's equaling 50% of the customers on feeder will produce just greater than the 1MW capacity. This is assuming a residence on a 15A at 120V. 15A at 120V is the voltage and amperage rating of a typical level 1 charging solution to electric vehicle owners which is most common. In the near future opportunities and predictable patterns may point to large fleet vehicles or large communities (geographically contained on a primary circuit).

Wide-scale adoption of EVs will influence distribution system operations and ultimately design. We need to recognize all distribution circuits, in time, will adopt the same level of penetration. This is because the aggregate of all the loads despite location will have the same load on the circuit as a whole which is seen at the substation transformer. Levels of penetration could exceed the loads beyond what current circuit is designed to handle. In order to meet these new demands, utilities must perform these levels of analysis to understand contingency plans as well as quantify the opportunities to mitigate.

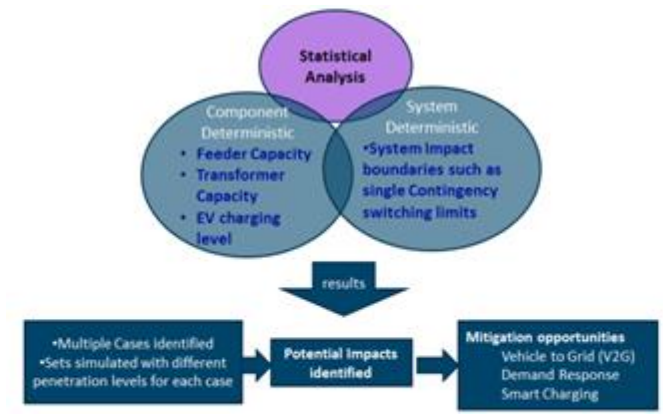

Figure 6 Methodology for determining impact and correlating the impact with mitigation opportunity

With this in depth method of the technology Electric Vehicles, supports the framework to move forward to how these opportunities to mitigate would work with other smart grid technologies.

4.2.1 Vehicle to Grid Modeling (V2G)

While electric vehicle analysis is the primary focus on how to connect the vehicles to the grid, which from a utility perspective is an issue in itself in both short and long term capacity. Future V2G technology will be added to the mature models to study the aggregation of the storage capability and how electric vehicles could provide support to the grid. Another important part of this method of analysis is that it will support one of the many benefits of consumers to utilize smart metering for the two way communication for control and demand response from customer to Utility operators. Mature models with high penetration parameters loaded will be supporting optimal TOU charging and discharging times. Algorithm results to optimize optimal TOU will be offset to PNMs seasonal system peak load.

4.3. High PV analysis

High penetration levels of photovoltaic (PV) generation on the utility grid have become a challenge for engineers in the planning areas. Several factors are identified and have to be considered as to understand the response of high PV penetration. Some parameters or characteristics of a feeder that have an effect on the measure of impact of high PV penetration are the circuit size, location, and the geographic distribution of the PV system. Impacts of concern include voltage, Demand, protection, power quality, and many more. The impact is a function of the characteristics of each circuit. Characteristics of the circuit include: topology, voltage level, power delivery and control elements, and load.

Circuit characteristics are a key underlying factor in the circuit response from distributed PV. The overlying factors are the PV size, location, and output. The distribution connected PV will ultimately mold the overall circuit response. The number of unique combinations of circuit characteristics and PV deployment make it difficult to imply that the response from one circuit will cause a similar response on another. The analysis methodology for the DPV project is discussed in detail to illustrate the procedure in which all impact factors can be fully analyzed. Utility support has provided circuits, each with 1-2 unique characteristics. These circuits are then each analyzed with a wide range of PV deployments. The analysis incorporates the distributed impact from a wide range of smaller residential PV systems in addition to larger utility scale type systems. The general results aggregated from the analysis will help identify the most critical characteristics for each of the issues described above. The specific circuit impact(s) will determine the appropriate PV penetration limit/hosting capacity.

This analysis has the opportunity to become a parameter of other technologies. Meaning that the hosting capacities determined by characterizing and methods of analysis could change when working against other technologies such as smart inverters, energy storage, etc.

4.4. Energy Storage

Energy Storage has been around for years in terms of Hydro for dams and is really defined as any method of storing energy and dispatched at a later time. In the past decade, opportunities have surfaced for technologies to support storage on the utility grid targeting both grid scale and residential.

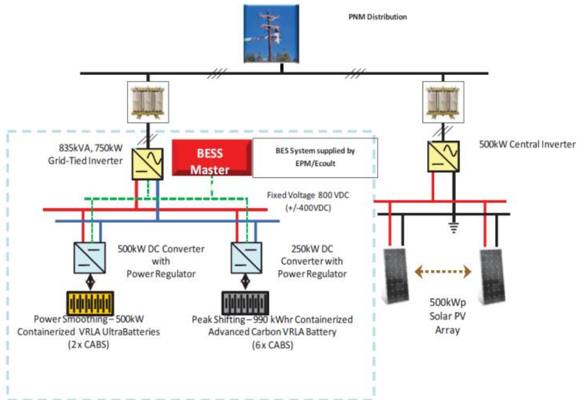

Figure 7 One line Diagram of Energy storage system.

PNMs Prosperity Energy Storage project is one of demonstration with assistance from

DOE funding helps to address the challenge of renewable energy reliability and to develop methods to manage solar energy.   This section of energy storage will go in to detail of the project, goals, and results to identify the impacts, solutions and mitigation opportunities that will ultimately be used in conjunction with other smart grid technologies on the utility grid.

Key components of the project:

- 500kW PV installation with 2,158 Schott 230 solar panels
- 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.

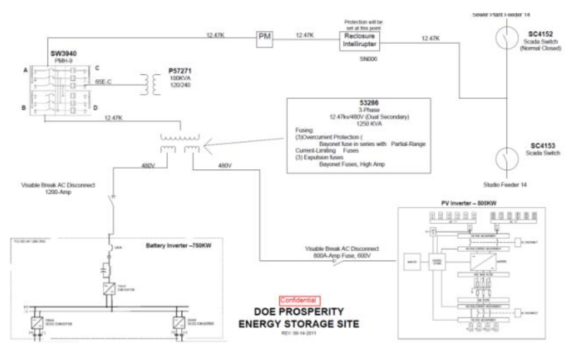

Figure 8 Online Diagram

  - 2 Battery Containers each containing 160 UltraBatteries™– with an power smoothing functionality
    - 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 (Power Conditioning System) is 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 of 30 samples per second
    - 1 second interval utility grade metering on the PV, Battery and overall site.
    - Secure gateway managing point collection of protocol translations (MODBUS & DNP3)
    - Secure 2 way communication to the utility's Distribution Operations
    - Secure fiber connection to Utility's Data Center
    - Back office PI database with real time access through Utility's internal sharepoint portal

- Energy storage system was built to change configuration from "end of feeder" to "start of feeder"

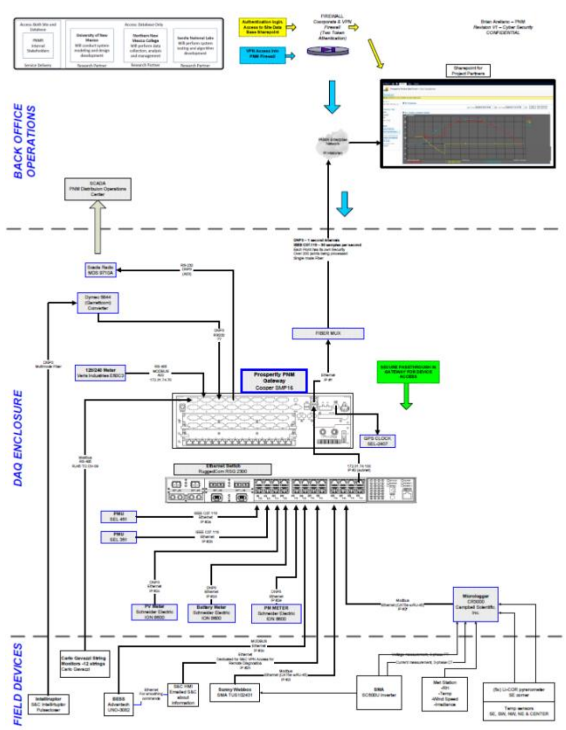

Figure 9 Communication architecture diagram

The Data Acquisition system diagram (see Figure 9) shows the system architecture and devices. The gateway is made up of a Cooper SMP with two Network Interface Cards (NICs). One NIC 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 IEEE C37.118 for the PMUs. 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 below:

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:
        i. Met Station (RH, Temp, Wind Speed, Irradiance)
        ii. 5x LI-COR Pyranometer
        iii. 5xTemperatore Sensors

The Energy storage project is a genesis of underlying efforts that began in 2008 at PNM that was supported by the EPRI Smart Grid Demonstration Program. In this EPRI collaboration extensive case analyses were developed to understand the broad communication/control schemes and solutions that would incorporate high penetration solar.

Energy storage applications and functions are key in identifying multiple benefits.

- Energy Shifting by enabling through peak shaving and firming. This is done by using different key source signals or parameters into the algorithm
- Area regulation is enabled through the Area Control Error signal into the algorithm. This is future work and is being studied right now. With the demonstration described by this project, this is a small grid scale energy storage project so the results would be scalable to identify the benefit.
- Voltage support is enabled by both shifting and smoothing of the energy storage piece of the project. Shifting by shifting energy to high peak times and smoothing PV intermittency caused by clouds.
- T&D Deferral is also known as reliability benefits. This is accomplished by peak shaving and incorporation of distributed resources to relieve substation service requirements.
- Capacity firming can be done with a renewable like PV by firming the energy to align production to utility system peak
- Arbitrage is monitoring pricing to establish thresholds to command power reserve or power dispatch during high and low pricing times.

The main benefits from this project include deferring peaking generation resources and their investments. The benefits derive from the avoided costs of a resource such as a peaking resource. With energy storage coupled with a renewable such as PV can create a reliable, dispatchable renewable resource. Can also reduce electric line loss depending on the location of the generation of the dispatchable renewable. The variety of benefits identified in this paper are mainly using the shifting function in which an advanced algorithm takes multiple parameters and priority decision making based on thresholds and parameters.

Deferring generation capacity investments, is really showing the ability of the system, as a firm peaking resource. This avoids fossil based peaking resource additions. By establishing a firm resource from PV a much higher capacity can be allowed these systems in resource planning. These benefits will be measured by the success of targeting an increase in allowable peak contribution of PV (from 55% current to 90% - typical of a gas peaking unit).

Deferring distribution capacity investments can be done by smoothing function from the batteries. 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 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.

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 PNM Technology Performance Report associated with an SOX, and NOX.

In addition to smart grid functions and benefits with energy storage, Cyber security is extremely important in the control system. The plan implemented to the energy storage project 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. Example of a in depth cyber security plan is a nine phase that consists of 183 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

Methodologies for Energy storage 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.

The analysis objectives are based on two main targets. One is to demonstrate the energy shifting to the typical peak (firming) by planned dispatch from the battery and also to demonstrate the shifting to the substation circuit (peak shaving) by planned dispatch from the battery. Another target is to simultaneous smooth the PV output by the fast responding counter action from the smoothing battery.

Other targets that are mentioned in this report are:

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

Test plans were developed based on the target objectives described above. The smoothing plans set goals of maximizing avoided cost benefits and maximizing lifetime of the battery. At the same time the system will be attentive to different economic parameters from the utility.

Summary of test plans:

- 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.
- Shifting PV for Firming Purposes - (day ahead) Demonstrate ability to shape PV-battery system output to optimize the value of the PV energy delivered.
- Peak Shaving– demonstrate a 15% reduction in the feeder peak load through peak shaving
- Energy Arbitrage – demonstrate response to price signals based on set high and low price thresholds.
- Optimized shifting and smoothing – combining and optimizing all functionality.

Technical Methods of evaluating performance of test plans

Smoothing algorithm optimization's effort targeted the optimal mode for smoothing by looking at three different smoothing schemes. One is lagging moving average, and another is centered moving average and lastly, Low Pass Filter. In order to determine the optimal scheme to address ramp rates of PV at the same time determine at what value will smooth enough to eliminate voltage fluctuations. In this paper, we will use the Load Tap Changers (LTC) at the substation to show at what level of smoothing defers an operation.

The analysis performed by in a Matlab environment using the one second data from the PV and Primary Meter was used to calibrate the model (before and after) to determing the delta Along with Matlab, OpenDSS was used to determine the effects of LTC operations at the substation transformer. Measurements were made based on cloud cover, medium cloud cover and no cloud cover for a variety of gain values for smoothing.

Results of performance test plans

Figure 10 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.

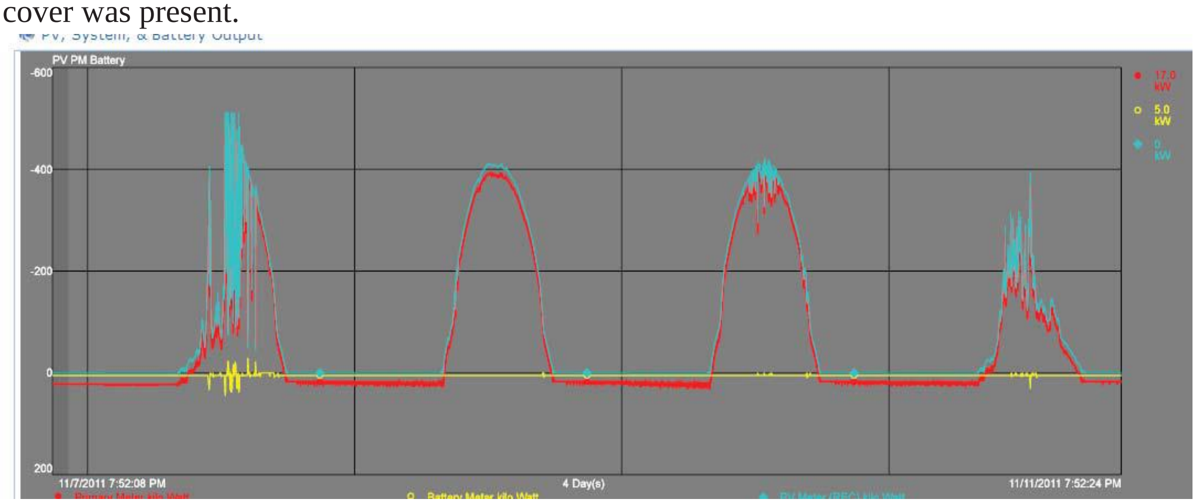

Figure 10 System output with battery system smoothing at 10%

When the System was run at 100% of the PV Meter as an input signal, Figure x2, 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. Some spiking occurred because of late response of the smoothing battery, as shown in a magnified view in Figure 13 the magnified view of second day of the data set.

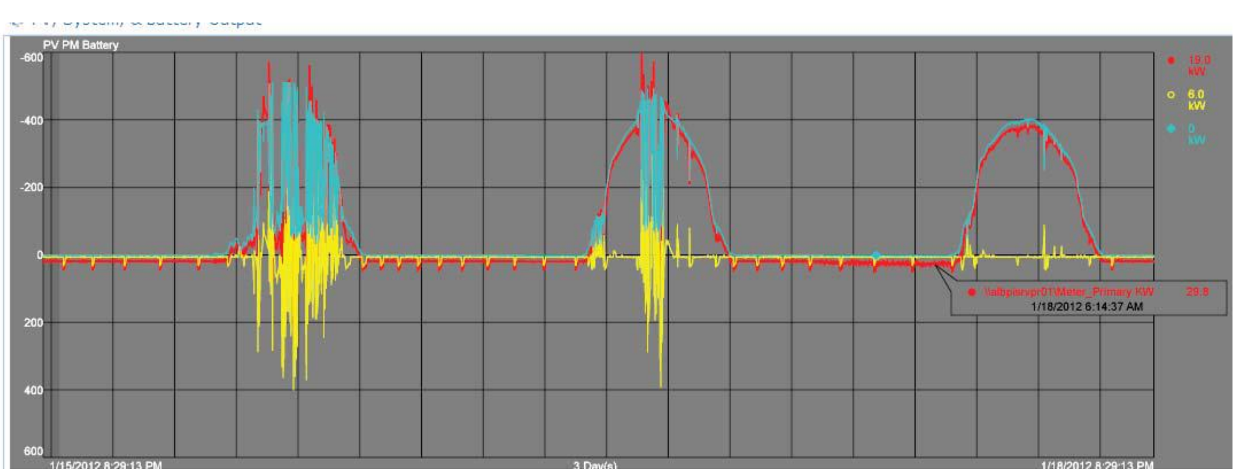

Figure 11 System output with Battery system smoothing at 100%

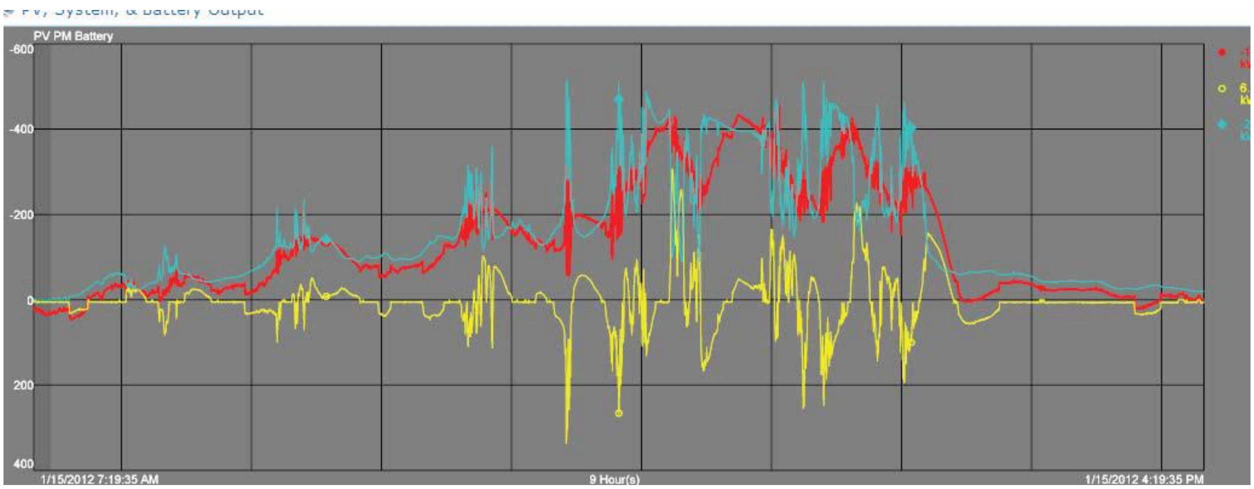

Figure 12 smoothing but the introduction of Latency in communication system

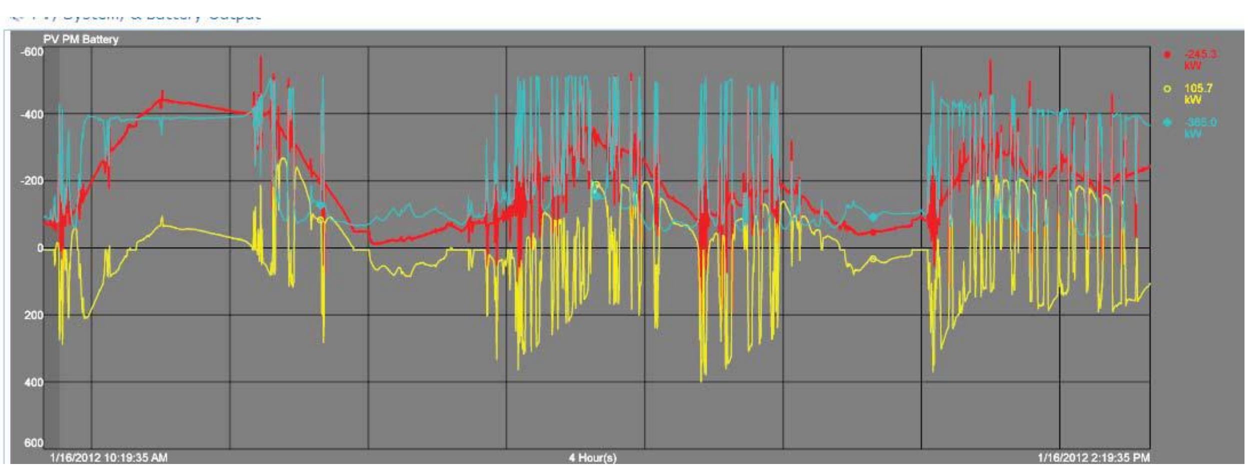

Figure 13 Smoothing with extreme latency issues as well as cloud enhancement shown on PV output ceiling at 500kW.

Comparing methods of smoothing algorithm

Using the Low Pass Filter (LPF) or Moving Average (MA) function. This effort was expanded to further test and compare the effects of ramp mitigation for different battery capacities. Cumulative Distribution Function (CDF) analysis was performed on various data sets utilizing a

01/03/2012 Dataset

Algorithm	Disp. Energy (kWh)	Percent of Worst Case
Lagging MA	89.75	83.51
Centered MA	43.14	40.13
LPF	107.48	100

12/18/2012 Dataset

Algorithm	Disp. Energy (kWh)	Percent of Worst Case
Lagging MA	312.5	88.2
Centered MA	245.6	69.4
LPF	354.3	100

Figure 14 Energy Usage with 3 different algorithms schemes

MATLAB model that was calibrated to field operation. Validation of the model after calibration yields the following correlation where a strong correlation is evident when predicted output is contrasted to actual field measurements.

LTC Operations Result from OpenDSS				
Case #	Day	PV, %	Energy Storage Scenario	Operations count
ES 1	1	14	2 of 250kW at feeder head	411
ES 1	2	14	2 of 250kW at feeder head	355
ES 1	3	14	2 of 250kW at feeder head	319
ES 1	4	14	2 of 250kW at feeder head	189
ES 2	1	14	20 of 250kW at secondary	411
ES 2	2	14	20 of 250kW at secondary	355
ES 2	3	14	20 of 250kW at secondary	319
ES 2	4	14	20 of 250kW at secondary	189
ES 3	1	14	200 of 2.5kW behind meter	411
ES 3	2	14	200 of 2.5kW behind meter	355
ES 3	3	14	200 of 2.5kW behind meter	319
ES 3	4	14	200 of 2.5kW behind meter	189
ES 4	1	14	200 of 2.5kW behind meter - smoothing	374
ES 4	2	14	200 of 2.5kW behind meter - smoothing	380
ES 4	3	14	200 of 2.5kW behind meter - smoothing	323
ES 4	4	14	200 of 2.5kW behind meter - smoothing	201
ES 5	1	14	Combined ES 2 and ES 4	390
ES 5	2	14	Combined ES 2 and ES 4	380
ES 5	3	14	Combined ES 2 and ES 4	281
ES 5	4	14	Combined ES 2 and ES 4	195

Figure 15 LTC operations baseline results

Some results from Prosperity metered data do, however, point to a reduction in operations. Figure 25 below shows two intermittent days where smoothing is disabled (left) and enabled (right). Load tap changer operations are evident 4 times in the left graph with moderate PV intermittency for the measured day and battery smoothing disabled. The evidence of the tap change is the rapid shift in circuit voltage. In the right side, where smoothing is enabled, only 1 tap change is evident when heavy intermittency is experienced.

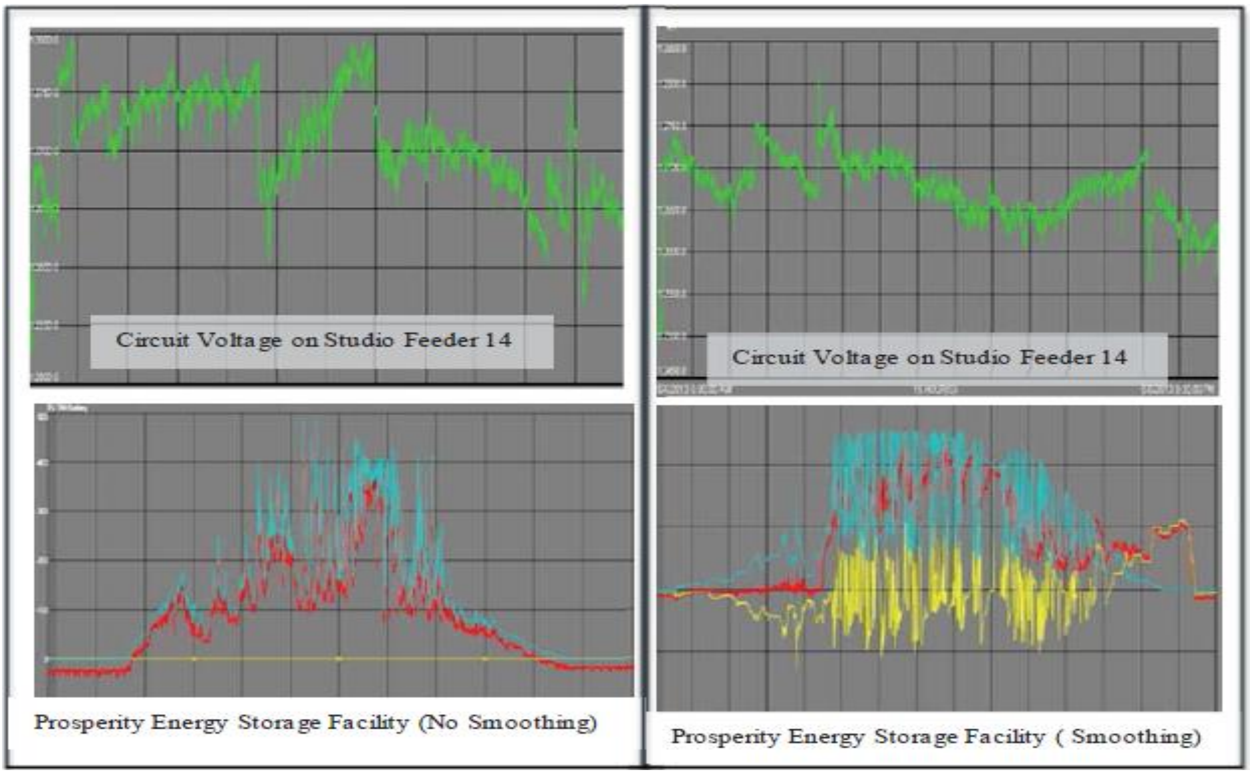

Figure 16 Voltage Profiles with and without smoothing showing LTC operations

When actual LTC operations for the feeders associated with Prosperity were analyzed no apparent trend of decreasing operations due to PV and smoothing was apparent.

Key Observations for 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.

- The 10% setting produced no discernible effect, however the 40, 60, 80 and 100% settings had noticeable effects on smoothing
- 40% smoothing has, according to the CDF analysis, similar effects on smoothing compared to 60, 80 and 100%
- 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 results presented are particular to this feeder, the amount of PV installed on the feeder as well as the nature of the feeder loads. Other feeders need to be analyzed individually to determine the amount of smoothing needed.
- Dynamic (OpenDSS) and static (Synergee®Electric) models will need to be relied upon to understand 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 Using irradiance sensors to smooth may also conflict with the duties of the Maximum Power Point Tracking function of the PV inverter.
- 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
- The LTC operations seem to be a lot more load dependent on both feeders analyzed than on PV. Also it should be noted that the LTC operates based on the substation

Shifting results

The individual and combined results of applications under the shifting realm, including Firming, Peak Shaving, Arbitrage and prioritized delivery of all of the above follow – Below is beta testing early on in the project

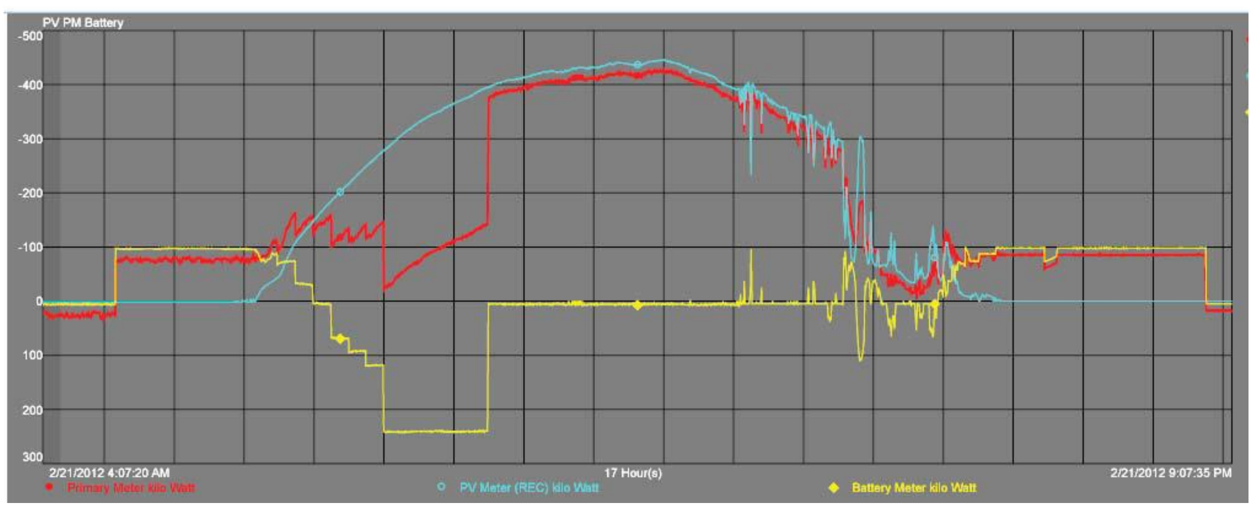

Figure 17 Beta Shifting testing diagram

The firming production from the battery began at 5am and it can be seen graphically in Figure. 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 not granular enough.

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. Figure 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.

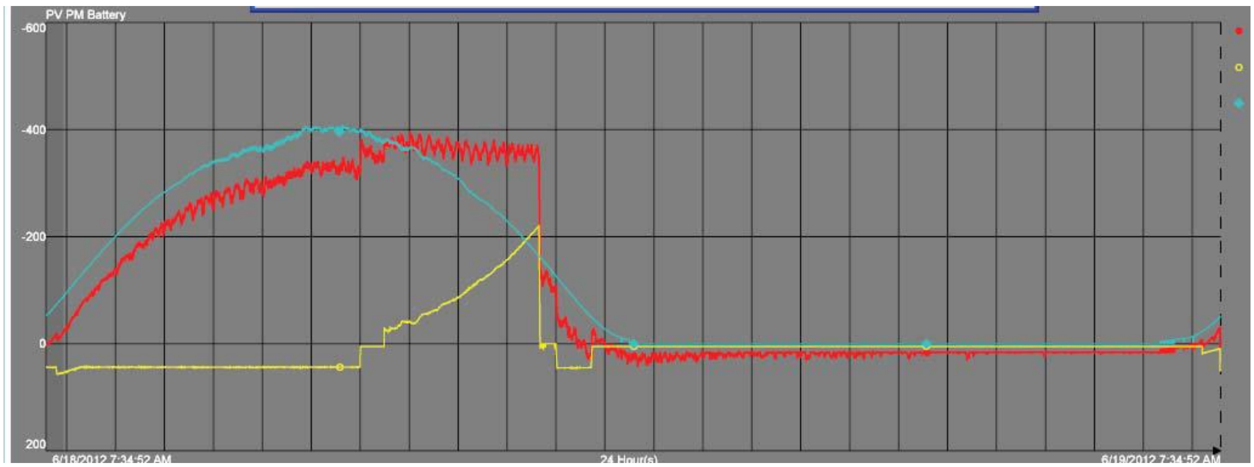

Figure 18 automated energy shifting

Key observations for Shifting/Firming

- 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 asked that the sharp drop off in the evening (summer schedule) obvious in Figure 30 be mitigated. This drop off was mitigated in later version to ramp down over 15 minutes.

Peak Shaving

The project data acquisition system has been gathering SCADA based meter data from 3 separate feeders, Tramway, Sewer Plant 14 and Studio 14. The latter two feeders can be fed by the PV Storage system based on the configuration of a SCADA switch. The Tramway feeder was selected because it is currently classified as a high penetration PV feeder. The shifting algorithm was modified to look at recent feeder history and forecast the feeder’s next day shape, accounting for the forecast next-day temperature. It then schedules and dispatches battery energy in order to shave a target 15% off of the feeder peak.

Initial attempts at peak shaving showed inaccuracies in the algorithm's forecast and the resulting outcome failed to shave the entire peak. This resulted in a residual peak appearing after the batteries finished discharge obviating any benefit from the batteries. In Figure below the Baseline is the Feeder Meter with the Projects Primary Meter data added back in – representing what the feeder would look like without the PV Storage Project.

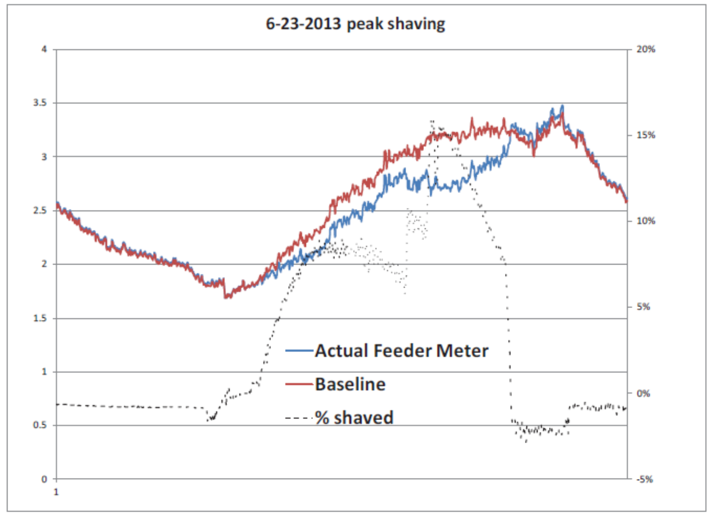

Figure 19 Peak Shaving Prior to Optimization

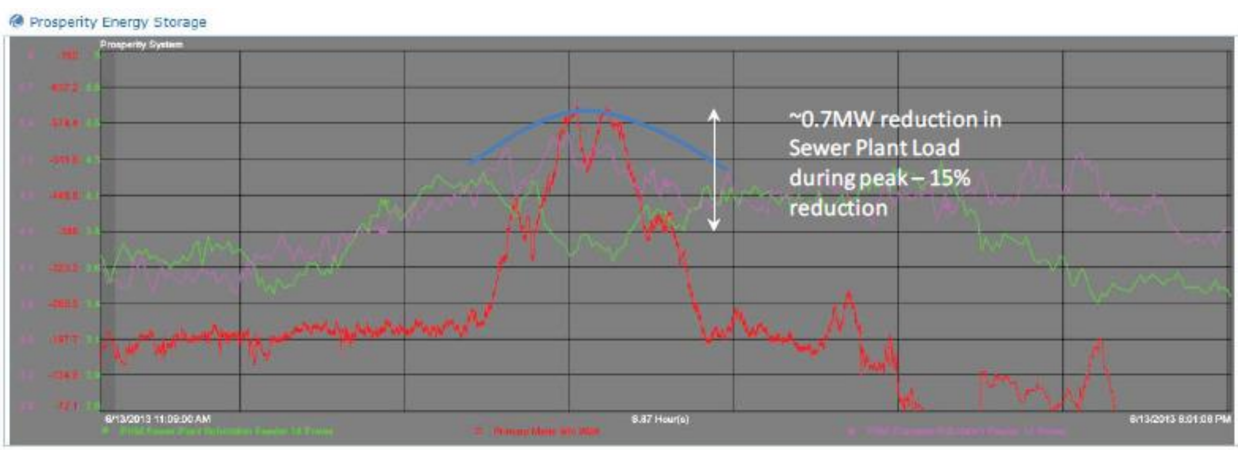

Figure 20 Peak Shaving After optimization

Key Observations for Peak Shaving

- The 15% reduction in feeder load goal was met after rigorous study and refinement of feeder profiles and optimization of feeder predictions. It was observed that only on hot days , when the feeder profile had a sharp predicted peak was the 15% reduction attainable. In cooler periods the load profile was too broad to achieve a 15% reduction – there wasn't enough energy available to achieve the goal in these periods.
- Acquiring the SCADA data into the project PI data base was not a straightforward exercise. Permissions were needed and software modifications were required in order to allow the transfer of PI TAGs from one database to another

- Weather (temperature) forecast data was needed in order to facilitate the prediction of the next day feeder load profile. The forecast profile was created by combining historical patterns, weather forecast and PV production forecast. First attempts had to be tuned to allow for an accurate feeder load profile prediction. First attempts resulted in battery dispatch profiles that ended too soon and allowed the feeder to peak close to status quo patterns.
- Analysis revealed that unless the peak ambient temperature was greater than 92 Deg F the percent of feeder peak shaved was less than 10%. This is because, for this feeder, the peak load profile flattens as the peak temperature drops.

Arbitrage

- Day ahead pricing should be preferred to capture the parameter needed in the algorithm to run against other priorities of energy shifting.
- A good approach is needed to acquire pricing due to misaligned database systems. (pricing source vs utility data source)

Prioritizing Operation of all applications

From all the analysis above in energy shifting, parameters are developed based on data inputs and functionality related to firming, arbitrage, and peak shaving. In order to create an efficient priority of the shifting algorithm, different thresholds are adjusted to compliment the priority of the system.

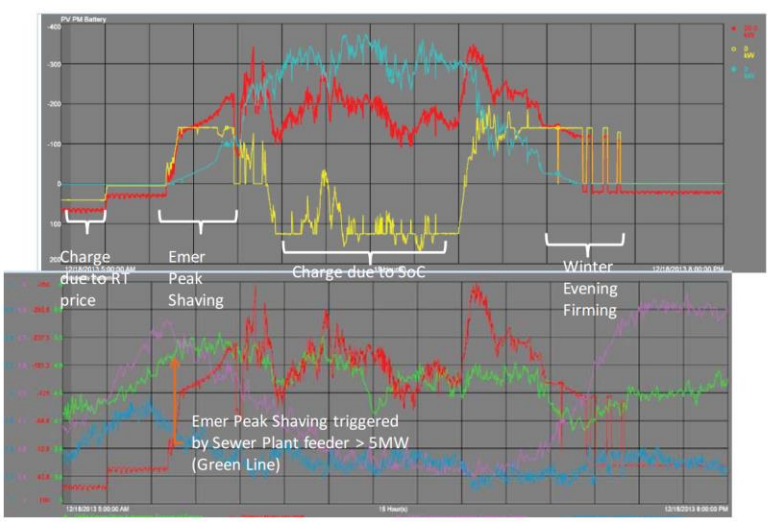

Figure 21 Output of Optimized operations

Prioritization operation of all applications of Energy Storage

There are 5 applications that can run in the prioritization basis:

- Emergency peak shaving
- Peak Shaving
- Arbitrage
- Wind Firming
- PV Firming

Other benefits not shown on this report

- Use Battery system for Volt/Var optimization
- Using System results to improve communication system latency
- Using Area Control Error signal as an input to the smoothing algorithm to address fast frequency response for directives of NERC BAL-003
- Coordinated control between other research on the same circuit such as microgrid operations and smart grid distributed resources.
- Implement a low cost Analsyis system to implement cloud forecasting in respect to smoothing applications to reduce energy usage in batteries.

5. Microgrid

The power industry began as micro-grids in the early 20th century as small unconnected to the power grid.   Due to the new technology and smart grid efforts in the industry there is new approaches to bringing back micro-grids.   With the need to improve the electric grid performance to associate with the growing number of distributed resource technologies, the need for control methods and advanced communication systems are needed.

Micro-grids are small systems that produce power and can operate independent of the utility grid. The DOE defines a microgrid as “A group of interconnected loads and distributed energy resources (DER) with clearly defined electrical boundaries that acts as a single

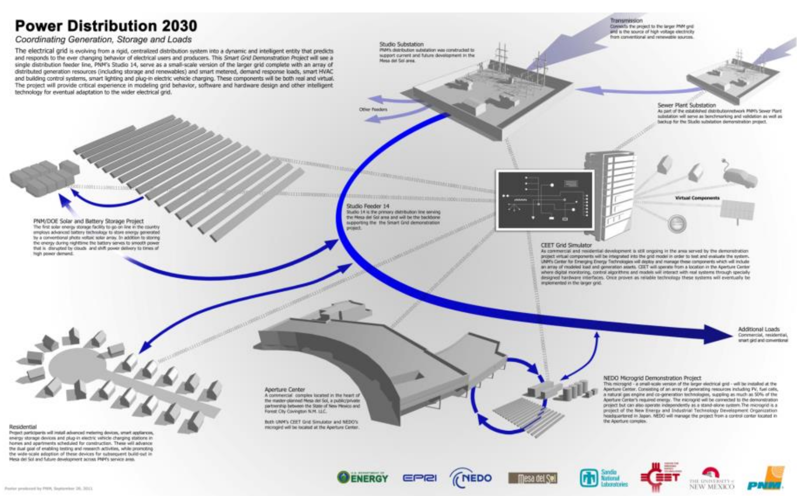

Figure 22 Micro-grid on PNM utility circuit with other Distributed Resources.

controllable entity with respect to the grid [and can] connect and disconnect from the grid to enable it to operate in both grid-connected or island mode."

They consist of multiple distributed technologies, such as solar, natural gas engines, and energy storage. Micro-grids can be designed to be the size of a single household and up to a system with a total load of 100MW. The opportunity identified is the potential for improving energy efficiency, reliability, power quality, and even cost of operation compared to traditional operations from the utility grid.

The growing distributed resources are bringing Micro-grids to the fore front of implementation and smart grid solutions in the utility industry. Although there are many constraints and parameters to understand the value of operational and control solutions, this paper will concentrate on coordinated control of energy storage with a microgrid on the same circuit. Diagram represents the multiple DG at Mesa del Sol in Albuquerque new Mexico. The microgrid is on the same circuit as the energy storage facility represented on this paper. Coordinated control between the two have been demonstrated by receiving inputs from the Microgrid DG and creating a coordinated control demonstration between the in order to simulate the coordination between grid scale energy storage and future microgrids.

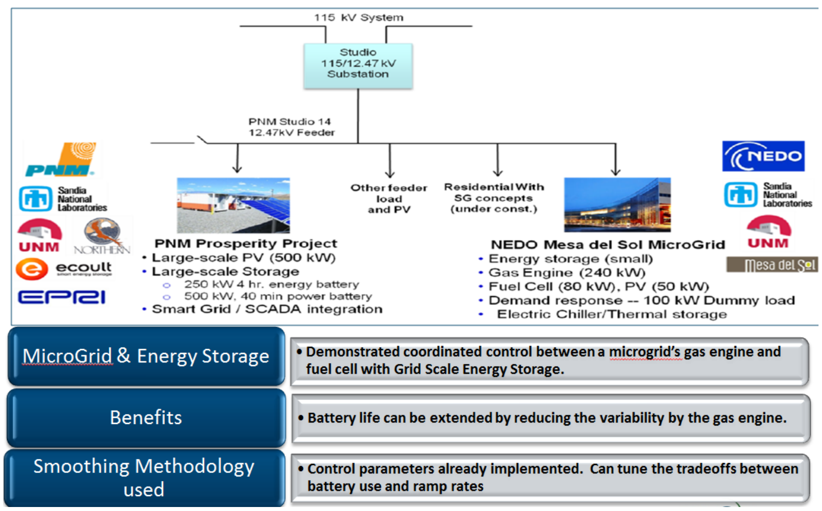

Figure 23 Micogrid distributed Generation in coordination with grid scale energy storage

6. Method for Implementation of multiple Smart Grid technologies

As stated early in this paper, there are multiple technologies and their communication methods that make up "smart grid". The ones represented here that I was involved with will be used to create a method of coordination for the benefits identified in this paper. I will demonstrate benefits and the opportunities for peak shaving, arbitrage, voltage mitigation, and firming using electric vehicles, energy storage and microgrids. This will be a methodology that will not only be limited to the DG listed here, but a method to introduce many more technologies such as gas turbines, smart inverters, etc.

Electric vehicles smart grid benefits was demonstrated around load control with time of use incentives and vehicle-to-grid, but what about peak shaving to defer the utility substation load that energy storage has proven viable and beneficial? Arbitrage with Electric vehicles is another example of a potential benefit.

The method for implementing smart gird technologies starts in the communication and architecture that links each technology which is challenging enough. However, linking each technology together will introduce more resilience of the smart grid introducing multiple benefits beyond what is described with each particular research described in this thesis.

Example of additional benefits are ; Utility peak shaving with electric vehicles, demand response with electric vehicles, coordinated control between customers between electric vehicles and microgrids.

Users can reduce peak power on a typical substation circuit by making use of nighttime power supply from the grid. A value to the user is the economic advantage of charging given the opportunity for a low cost power supply. Utilizing V2G technology, discharging during peak hours can be an economic benefit for users/customers. This is also known as time-shifting and deferring capacity. Deferring capacity is reducing the utility peak load on the utility's circuit. Base-load generation is the targeted area to use to charge from the grid. Every circuit has its own characteristics, therefore has different peak characteristics based on time, shape and capacity. Smart Grid technology will have to read these parameters that define the characteristics of the circuit in order for peak shaving with EV to be efficient for the utility and economical for the user/customer.

The demonstration of energy storage outlined in this paper had multiple demonstrations such as smoothing, arbitrage, firming, and peak shaving. Peak shaving produced most value out of all the applications. Due to analysis modeling the deferment of shaving the peak to reduce load capacity on a targeted circuit. This is due to PV misalignment system peak load and still growing loads. The value can target a peak specifically similar to that of the benefit of V2G peak shaving using clustered electric vehicles.

Arbitrage utilizing electric vehicles can be a benefit to both customer and utility. Arbitrage would be a realized benefit to the customer when there presents an opportunity to charge a vehicle when there is a lower cost on the electric grid. Then a customer could dispatch when needed on the utility when the charging is high but the opportunity to sell back to the electric grid when grid is stressed such as during peak times. The stress to the grid correlates with peak shaving identified on the V2G above. Standards and regulation of the utilities are not mature for this mitigation opportunity for the utility and TOU rates defined to enable this function, however the opportunity and benefit is clear. Arbitrage is very similar to the parameters to determine peak shaving but target cost for the customer and reliability to the utility. Similar to peak shaving above, utilizing V2G technology, discharging during peak hours can be an economic benefit for users/customers as well with Arbitrage. This is also fits the goal of time-shifting and deferring capacity. As mentioned above, deferring capacity is reducing the utility peak load on the utility's circuit. Base-load generation is the targeted area to use to charge from the grid, which supports the V2G of EVs to discharge using cost as a reference. Smart Grid technology will have to read these similar parameters that define the characteristics of the circuit in order for peak shaving as well as Arbitrage with EV to be efficient for the utility and economical for the user/customer.

7. Conclusions and future work

Future work concentrates on communication and management systems. Management systems that will take each smart grid technology and target load reduction from generation as well as solving for reliability needs utilizing each technology. Also the communication infrastructure needs to be in place in order to send parameters, status, and benefit needed at the time based on customer demands and mitigating any economical impacts such as price reduction for generation.

Publications by author

1. "Modeling of PV Plus Storage for Public Service Co. of New Mexico's Prosperity Energy Storage Project", O. Lavrova, F. Cheng, B. Arellano, Sh. Abdollahy, A. Mammoli, *Electrical Energy Storage Applications and Technologies Annual meeting*, San Diego, CA, October 17-19, 2011
2. "Applying Battery Energy Storage to Enhance the Benefits of Photovoltaics". IEEE, Energy Tech 2012.S. Abdollahy, Student Member, IEEE, O. Lavrova, Member, IEEE, A. Mammoli, S. Willard, B. Arellano. A Comprehensive Approach Toward Distribution System Forecasting. 2011
3. "Analysis of Battery Storage Utilization for Load Shifting and Peak Smoothing on a Distribution Feeder in New Mexico" O. Lavrova, *Member, IEEE,* F. Cheng, Sh. Abdollahy, *Student Member*, *IEEE,* H. Barsun, A. Mammoli, D. Dreisigmayer, S. Willard, B. Arellano, C. van Zeyl. 2011
4. "Modeling of PV plus storage for peak shifting and simultaneous smoothing at Mesa del Sol". O. Lavrova, F. Cheng1, Sh. Abdollahy, A. Mammoli, S. Willard, B. Arellano, J. Hawkins D. Dreisigmeyer, C. van Zeyl. 2011
5. "PNM Smart Grid Demonstration Project from Modeling to Demonstration." S. Abdollahy, Student Member, IEEE, O. Lavrova, Member, IEEE, A. Mammoli1 S. Willard, B. Arellano.. 2011
6. "Real-Time Control of Utility-Scale Storage on a Distribution Feeder with High PV Penetration." S. Abdollahy*, Student Member IEEE*, B. Arellano, H. Barsun, F. Cheng, D. Dreisigmayer, J. Hawkins, *Member IEEE*. O. Lavrova, *Member IEEE,* A. Mammoli, B. McKeon[5], S. Willard, J. Wood, C. van Zeyl. Department of Electrical and Computer Engineering, University of New Mexico, Public Utility Service Company of New Mexico (PNM), Department of Mechanical Engineering, University of New Mexico, Northern New Mexico College, Ecoult, East Penn Manufacturing. 2011
7. PV output smoothing with energy storage; Ellis, A. ; Schoenwald, D. ; Hawkins, J. ; Willard, S. ; Arellano, B.; Photovoltaic Specialists Conference (PVSC), 2012 38th IEEE; Publication Year: 2012 , Page(s): 001523 - 001528
8. "A modeling framework: Analysis of Electric Vehicles in New Mexico urban utility distribution infrastructure", B. Arellano, S.Sena, J. Hawkins, *O. Lavrova*, Submitted to IEEE TRANSACTIONS ON SMART GRID, Special Issue on Energy Storage , accepted for publication
9. "A framework, modeling and impact analysis of Electric Vehicles in New Mexico urban utility distribution infrastructure", S. Sena, B. Arellano, S. Abdollahy, O. Lavrova, J Hawkins, DOE SunShot Initiative Summit and Technology Forum, Denver, CO, June 13-14, 2012
10. "Analysis of Electric Vehicle Impacts in New Mexico urban distribution infrastructure" , Brian Arellano, Santiago Sena, Shahin Abdollahy, Olga Lovrova, Sara Stratton, Jon Hawkins. IEEE Transportation Electrification Conference and Expo (ITEC 2013). Accepted paper
11. "Energy Storage Enhances PV Plant", Brian Arellano – PNM Resources, Jonathan Hawkins – PNM Resources, Clerverson Takiguchi – S&C Electric

Europe Ltd, Flavio Lopes Jr – S&C Electric Company Ltd. Southern African Energy Efficiency Convention (2014SAEEC). Accepted paper, August, 2014.

Presentations by author

1. "PNM Substation Hardening & Security", EPRI: Incident Management Task Force Webcast. Webinar. May 28, 2014
2. "PNM/UNM Modeling and Smart Grid Projects". Power Delivery Utilization. Integration of Distributed Renewables (P174). February 10, 2014.
3. "Smart Grid and Technology in the utility" PNM IRP Presentation Q1 2014.
4. "GIS Converter" Innovation award. PNM. CEO & Board of Directors, July 15, 2014
5. "Station Hardening and Security: PNM Case Study". UTC Conference May 8th, 2014. Phoenix Arizona.
6. "Storage for Simultaneous Voltage Smoothing and Energy Shifting". Presentation on Forum: Energy Development and Power Generation & Intelligent Grid Forum. 2014 IEEE PES T&D Conference. Chicago Il.
7. "Impact of GIS Data Quality on Determining the benefits of advanced smart grid applications", Distributech. January 28, 2014.
8. "Importance of GIS Data Quality: The Impact of GIS Data Quality on Determining the Costs and Benefits of Advanced Smart Grid Application, Brian Arellano, PNM", EPRI Smart Distribution and Power Quality Conference, Chicago, IL, June, 2013.
9. Energy Storage Panel: "Is Energy Storage the Answer?" Utility Solar Conference, Portland, OR, April 2013
10. "Enhancing PV with Energy Storage", Smart Grid Demonstration Advisory Meeting (EPRI), Tempe, AZ. 2013.
11. "Prosperity Energy Storage, EPRI, Sharepoint", PNM Operations All Hands Meeting, May, 2013
12. "The Impact of GIS Data Quality on Determining the Benefits of Advanced Smart Grid Applications", EPRI Geospatial Information System Interest Group Webcast, October 24, 2013
13. "Is Energy Storage the Answer?" Energy Storage: Implementing PV Smoothing and Shifting Simultaneously. Utility Solar Conference (SEPA). Portland, Oregon. April 16, 2013
14. Expanding and Integrating Renewable Energy in New Mexico: Challenges and Opportunities. 2012 Natural Resources Speakers. Natural Resources Program at the UNM School of Law, Utton Center and Environmental Law Society. UNM Law Department, Albuquerque, New Mexico, October 2012
15. PV Plus Storage for Simultaneous Voltage Smoothing and Peak Shifting: Energy Storage EPRI Program at Power Delivery & Utilization Fall Program Advisory Meeting. Atlanta Georgia, September 2012
16. Maximizing Benefits of Energy Storage: Packaging Storage for Distribution Energy and Microgrid Solutions. Storage Week, San Jose Ca, June 2012

17. A framework, modeling and impact analysis of Electric Vehicles in New Mexico urban utility distribution infrastructure: SunShot/DOE, Denver, Colorado, June 2012
18. Integrating Utility Based PV and Storage on a Smart Grid Foundation: Smart Grid and Solar- Will Advances in Smart Grid Help Utilities Manage Solar? SEPA, Tucson, Arizona, April 2012.
19. PNM Prosperity PV Storage Project: ECE 595 Photovoltaics Class for University of New Mexico. Albuquerque, New Mexico. 2012
20. PV Smoothing and Shifting Utilizing Storage Batteries Case Study. EPRI. Smart Grid Demonstration Project Advisory Meeting. Houston, Texas, March 2012.
21. PV Plus Storage for Simultaneous Voltage Smoothing and Peak Shifting. U.S. Department of Energy Systems Program (ESS). San Diego, California, October 2011.

References

[1] OpenDSS manual: http://sourceforge.net/projects/electricdss/
[2] [1] http://sourceforge.net/projects/gridlab-d/
[3] [1] http://synergee-electric.software.informer.com/
[4] [1] http://www.powerqualityworld.com/2011/04/ansi-c84-1-voltage-ratings-60-hertz.html
[5] Lavrova, O., Cheng, F., Abdollahy, S., Barsun, H., Mammoli, A., Dreisigmayer, D., & van Zeyl, C. (2012, January). Analysis of battery storage utilization for load shifting and peak smoothing on a distribution feeder in New Mexico. In Innovative Smart Grid Technologies (ISGT), 2012 IEEE PES (pp. 1-6). IEEE.
[6] Cheng, F., Willard, S., Hawkins, J., Arellano, B., Lavrova, O., & Mammoli, A. (2012, May). Applying battery energy storage to enhance the benefits of photovoltaics. In Energytech, 2012 IEEE (pp. 1-5). IEEE.
[7] Li, Nein-Yi, Doug Collins, Shashank Jatar, Olga Lavrova, Chris Helms, Wenlin Luo, Linlin Liu et al. "Design and manufacturing of 10G GenX VCSELs at Emcore." In Integrated Optoelectronic Devices 2007, pp. 648402-648402. International Society for Optics and Photonics, 2007.
[8] Li, D., Jayaweera, S. K., Lavrova, O., & Jordan, R. (2011, April). "Load management for price-based demand response scheduling-a block scheduling model". In International Conference on Renewable Energies and Power Quality (ICREPQ'11),(Las Palmas de Gran Canaria, Spain).
[9] Mammoli, A., Jones, C. B., Barsun, H., Dreisigmeyer, D., Goddard, G., & Lavrova, O. (2012, May). Distributed control strategies for high-penetration commercial-building-scale thermal storage. In Transmission and Distribution Conference and Exposition (T&D), 2012 IEEE PES (pp. 1-7). IEEE.
[10] Lavrova, Olga A., and Daniel J. Blumenthal. "Accelerated aging studies of multi-section tunable GCSR lasers for dense WDM applications." Lightwave Technology, Journal of 18, no. 12 (2000): 2196-2199.
[11] Gurevich, S. A., O. A. Lavrova, N. V. Lomasov, S. I. Nesterov, V. I. Skopina, E. M. Tanklevskaya, V. V. Travnikov et al. "ZnCdSe/ZnSe quantum well wires fabricated by reactive ion etching and wet chemical treatment." Semiconductor science and technology 13, no. 1 (1998): 139.
[12] Mason, B., Lavrova, O., Fish, G. A., DenBaars, S. P., & Coldren, L. A. (1998). "Sampled grating DBR lasers with integrated wavelength monitoring." Integrated Photonics Research, 98, 52-54.
[13] Osinsky, A., Y. Qiu, J. Mahan, H. Temkin, S. A. Gurevich, S. I. Nesterov, E. M. Tanklevskaia, V. Tretyakov, O. A. Lavrova, and V. I. Skopina. "Novel wet chemical etch for nanostructures based on II-VI compounds." Applied physics letters 71, no. 4 (1997): 509-511.
[14] Abdollahy, S., Lavrova, O., Mammoli, A., Willard, S., & Arellano, B. (2012, January). PNM smart grid demonstration project from modeling to demonstration. In Innovative Smart Grid Technologies (ISGT), 2012 IEEE PES (pp. 1-6). IEEE.
[15] Mammoli, A., Jones, C. B., Barsun, H., Dreisigmeyer, D., Goddard, G., & Lavrova, O. (2012, May). Distributed control strategies for high-penetration

commercial-building-scale thermal storage. In Transmission and Distribution Conference and Exposition (T&D), 2012 IEEE PES (pp. 1-7). IEEE.
[16]Abdollahy, S., Lavrova, O., Mammoli, A., Willard, S., & Arellano, B. (2012, January). PNM smart grid demonstration project from modeling to demonstration. In Innovative Smart Grid Technologies (ISGT), 2012 IEEE PES (pp. 1-6). IEEE.
[17]Aeby, Ian, Lei Yang, Olga Lavrova, Hai Ling, Doug Collins, Charlie X. Wang, Chiyu Liu, and Thomas Whittington. "VCSELs for high-speed data communication in TO packages: pushing the envelope." In Integrated Optoelectronic Devices 2005, pp. 91-100. International Society for Optics and Photonics, 2005.
[18]Lavrova, O., Cheng, F., Abdollahy, S., Mammoli, A., Willard, S., Arellano, B., & van Zeyl, C. (2011, October). Modeling of PV plus Storage for Public Service Company of New Mexico's Prosperity Energy Storage Project. In2011 Electrical Energy Storage Applications & Technologies Conference (EESAT), San Diego, CA.
[19]Abdollahy, S., Lavrova, O., Heine, N., Mammoli, A., & Poroseva, S. (2013, August). Integrating heterogeneous distributed energy resources to manage intermittent power at low cost. In Technologies for Sustainability (SusTech), 2013 1st IEEE Conference on (pp. 223-229). IEEE.
[20]Lavrova, O., R. Doshi, O. Jerphagnon, J. E. Bowers, V. Kaman, L. A. Coldren, and J. Barton. "All-Optical Label Swapping Networks and Technologies." J. Lightwave Technol 12 (2000).
[21]"Renewable energy and smart grid principles integration into campus–wide energy strategy at the University of New Mexico", O Lavrova, H Barsun, R Burnett, A Mammoli, International Journal of Technology, Policy and Management 12 (2), 212-232, 2012
[22]Kim, B., & Lavrova, O. (2013, May). Optimal power flow and energy-sharing among multi-agent smart buildings in the smart grid. In Energytech, 2013 IEEE (pp. 1-5). IEEE.
[23]Kim, B., & Lavrova, O. (2013, April). Two hierarchy (home and local) smart grid optimization by using demand response scheduling. In Innovative Smart Grid Technologies Latin America (ISGT LA), 2013 IEEE PES Conference On (pp. 1-8). IEEE.
[24]Hrdlickova, Kuckova S., Krizkova M. Crhova, C. L. Pereira, R. Hynek, O. Lavrova, T. Busani, L. C. Branco, and I. C. Sandu. "Assessment of green cleaning effectiveness on polychrome surfaces by MALDI-TOF mass spectrometry and microscopic imaging." Microscopy research and technique77, no. 8 (2014): 574-585.
[25]Lavrova, O. A., and D. J. Blumenthal. "Accelerated aging and reliability studies of multisection tunable GCSR lasers for dense WDM applications." InOptical Fiber Communication Conference, 2000, vol. 1, pp. 181-183. IEEE, 2000.
[26]Dencheva, Nadya, Hugo Gaspar, Sergej Filonovich, Olga Lavrova, Tito Busani, Gabriel Bernardo, and Zlatan Denchev. "Fullerene-modified polyamide 6 by in situ anionic polymerization in the presence of PCBM."Journal of Materials Science 49, no. 14 (2014): 4751-4764.

[27]“Coordinated Collaboration between Heterogeneous Distributed Energy Resources”, S Abdollahy, O Lavrova, A Mammoli - Journal of Solar Energy, volume 2014, 2014
[28]“Analysis of electric vehicle impacts in new Mexico urban utility distribution infrastructure”, B Arellano, S Sena, S Abdollahy, O Lavrova, S Stratton, J Hawkins, 2013/6/16, Transportation Electrification Conference and Expo (ITEC), 2013 IEEE, Pages 1-6
[29]“The integration of solar cells with PIFA for energy harvesting”, Y Tawk, J Erickson, F Ayoub, O Lavrova, CG Christodoulou, 2014/7/6, Antennas and Propagation Society International Symposium (APSURSI), 2014 IEEE, pages 1351-1352
[30]Rahimi, Nassim, Andrew A. Aragon, Darryl M. Shima, Christopher Hains, Tito Busani, Olga Lavrova, Ganesh Balakrishnan, and Luke F. Lester. "Characterization of surface defects on Be-implanted GaSb." Journal of Vacuum Science & Technology B: Microelectronics and Nanometer Structures 32, no. 4 (2014): 04E109-04E109.
[31]“New generation of biomorph integrated with TCO and thermoelectric to enhance efficiency in wide solar spectrum solar cell” , Matt Erdman, Kathleen Martin, Hope Quintana, John Shelnutt, Julio Martinez, Olga Lavrova, Tito Busani, 2014/6/8, Photovoltaic Specialist Conference (PVSC), 2014 IEEE 40th, Pages 1762-1765