TRANSMISSION AND DISTRIBUTION DEFERMENT USING PV AND ENERGY STORAGE

Mark Ralph[1], Abraham Ellis[1], Dan Borneo[1], Garth Corey[1], and Sara Baldwin[2]
[1]Sandia National Laboratories, Albuquerque, NM, USA
[2]Utah Clean Energy, Salt Lake City, UT, USA

ABSTRACT

It is often assumed that distribution-connected PV can help defer the need for distribution system upgrades, but there is not a general approach for assessing the deferment value of distribution-connected PV and distribution-connected PV combined with a storage system (e.g., battery). A vital component of such an analysis is time-coincident load and solar resource data, since load (especially peak load) is usually correlated with solar resource and temperature conditions, and both factors determine PV system performance as well. This paper demonstrates a methodology to analyze the value of using PV to defer distribution system upgrades. The paper also assesses the additional benefit of combining energy storage with PV to increase this deferment value. The case study involves replacement of a station transformer.

T&D VALUE OF PV GENERATION

At the local distribution system, PV generation reduces feeder and transformer load, as well as system losses. The reduction in load offers a possible opportunity for deferment of transformer replacement or other system upgrades. The deferment benefits are specific to the situation and require a study the actual load and solar resource for an accurate evaluation. Methodologies to estimate the T&D value of distribution-connected PV, including deferment value, has been explored before—see [1] for example. The value of energy storage has also been discussed extensively in the literature—see [2] for example. The potential synergy between PV and energy storage has not been discussed as much.

Several factors must be considered in the analysis of the deferment value of PV and PV combined with a storage system. These factors include:

- time-coincident solar and load profiles,
- the nature of the system limitations,
- utility business practices,
- other technical options available such as load transfer, and
- other non-technical factors or constraints

To the extent that the solar resource aligns well with the load profile, PV output can reduce system peaks and thus reduce the likelihood of overloads. It is often the case that PV output is not well aligned with the demand curve. If the peak load occurs at night, PV deployment alone would have no impact on the peak load. If the peak load occurs in during the day, increasing PV penetration may reduce peak load up to the point where the net load peak occurs in the evening. The capacity value is dependent on penetration level and the load shape. Integration of energy storage could be an alternative to further reduce system peak depending on the situation.

Combined deployment of PV and energy storage could provide a better overall business case compared to deployment of energy storage only. This is because the size of the energy storage system may be reduced. In this paper, a method for assessing the deferment value of PV and PV plus storage is presented. In addition to deferral value, PV and energy storage could provide a range of benefits that continue through the life of the PV system and energy storage systems.

ANALYSIS METHODOLOGY

For the analysis, data from several distribution stations in Salt Lake City were analyzed. The data included historical 15 minute load and solar resource data, load growth rate and station limits (transformer overload in this case). The historical load data and local solar irradiance data must be available for the same time period, and covered one recent operating year. PV output profiles were generated based on the solar resource data. The load duration curves with and without PV were compared to determine the capacity factor, which is a measure of how effectively PV reduces the peak load. PV penetration levels of 10% and 20% based on station rating were analyzed. The deferment value was estimated based on the hours of overload for each PV deployment scenario. The second part of the analysis involves evaluation of energy storage solutions for each PV deployment scenario, to achieve deferment of station upgrades. Figure 1 shows the calculation of net station load when both PV and energy storage are considered. For this analysis, the impact of feeder losses was ignored.

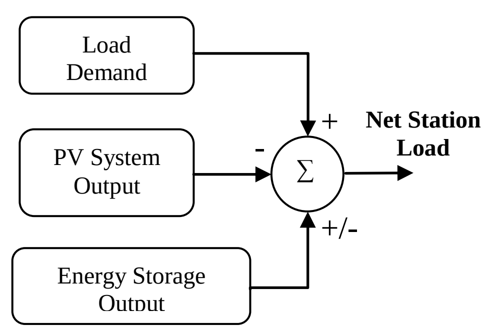

Figure 1 –Simulation Model

SOLAR OUTPUT MODEL

Solar Resource data for the operating year and for the same locality was obtained from the National Oceanic and Atmospheric Administration (NOAA) Integrated Surface Irradiance Study Network (ISIS) station in Salt Lake City [3]. The ISIS data includes:

- Direct Normal Irradiance
- Diffuse Horizontal Irradiance (DHI)
- Total Horizontal Irradiance (THI)

The ISIS solar resource data is collected at a 3-minute resolution. For the purposes of this analysis, the data was averaged over a 15 minute period for convenience (to match the 15 minute load data sampling rate), and to partially account for geographical diversity of distributed PV generation. There are more sophisticated approaches to account for geographic diversity, but this simple method was deemed to be sufficient for the purposes of this analysis.

A simple algorithm was implemented to estimate the PV array output. It uses the Ephemeris Equations [4] to calculate the sun position at the location of interest (Salt Lake City, in this case). The Angle Of Incidence (AOI) on the PV array can be calculated based on sun position and array orientation. Once the AOI has been determined, the direct and diffuse components of the Plane of Array (POA) irradiance and PV output can be calculated using the following equations [5]:

*Direct POA irradiance = DNI * cos (AOI)*

*Diffuse POA irradiance = DHI * (1+cos (ArrayTilt)) / 2 + THI *(0.012 .* Zenith - 0.04) .* ((1-cos(ArrayTilt))/2)*

*Solar Power Output = PV Rating * (Direct POA + Diffuse POA)*

where:

- ArrayTilt is the assumed average tilt angle of array with respect to horizontal in degrees
- Zenith is the zenith angle of the sun in degrees
- PV Rating is assumed to be the total AC rating

Figure 2 depicts the solar data processing procedure.

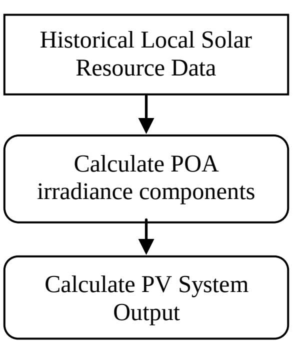

Figure 2 – Estimation of PV array Output

ENERGY STORAGE MODEL

Figure 3 shows the assumed operation of an energy storage system for a deferment application. The support window corresponds to the time period of the day where load is high and the energy storage system is armed to discharge. The recharge window is a period of time where load is low (night) and the storage system is programmed to recharge from the grid. During the charge and recharge periods, constraints such as the energy storage size (defined by the energy storage capacity and interface power rating), charge/discharge rates, and minimum state of charge (SOC) are respected.

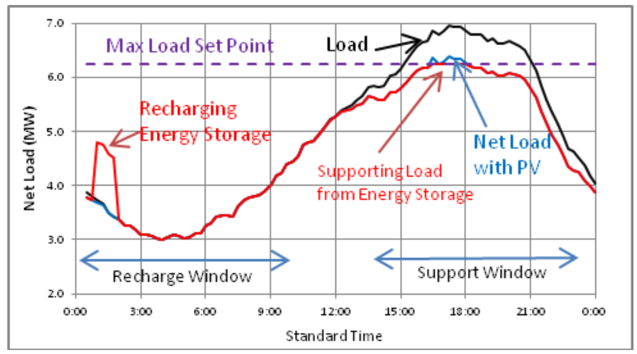

Figure 3 –Support and Recharge Windows

During the support window, the energy storage system could be scheduled to discharge at a pre-determined rate over the support period, or it could be programmed to discharge as needed to keep transformer load form exceeding a certain level. The latter control objective was used for this analysis. The net load is compared to a Max Load set point for the substation. If the load exceeds the set point, energy was discharged from the energy storage to reduce the net substation load to the maximum load set point. The discharge rate setting in the inverter controls may come into play.

During the recharge window, the charger will use energy increasing the net load on the substation. When the Energy Storage reaches a full state of charge, charging is stopped. A charging efficiency is used to account for inefficiencies in the Energy Storage system.

ANALYSIS FOR DEFERRAL VALUE OF PV

To assess the deferral value of PV on a feeder it is first necessary to obtain time-coincident load and solar resource data. Solar data at arbitrary locations is typically available as Global Horizontal irradiance. A PV array model is used to predict PV output from system configuration (tracking and module technology), solar irradiance and temperature. Finally, the net load (load served beyond a certain level of PV penetration) is calculated by subtracting predicted PV output from measured load at each time interval.

An example of the effect of PV output on net load is shown in Figure 4. These results show a commercial load profile for three consecutive days starting with a Sunday. Two levels of PV penetration (10% and 20%) and two orientations for a fixed latitude tilt array (facing due south and southwest) are shown. It is noted that orienting a fixed array southwest slightly shifts power production to later in the day so that the production might better match the load profile and have a larger impact on peak load reduction.

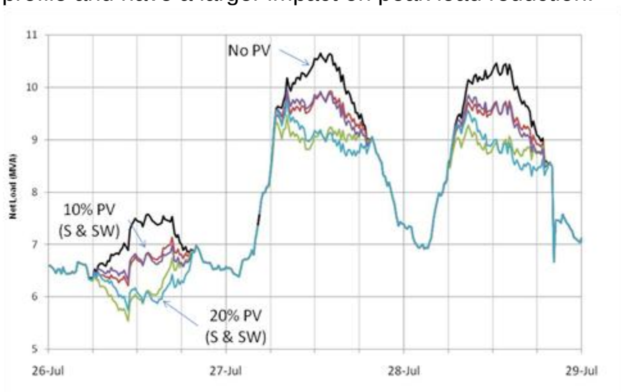

Figure 4 –Substation Net Load (black) with 10% and 20% PV penetration and orientation South (S) and Southwest (SW), assuming a fixed array.

The method for estimating the deferral value involves analysis of a full year of load data. The red curve in Figure 6 shows the upper portion of the load duration curve. High loading is of primary interest since we are interested in peak load reduction. The green curve shows the net substation load with 20% penetration of PV. The Capacity Value (CV) of the PV can be inferred from the reduction in the load duration curve of the substation or feeder with and without PV. As shown in Figure 5 the effect of adding a PV array to reduce the load on the substation so that the overload is less than some acceptable level for some acceptable period of time (1% in this example). The paper will describe the technical reasons why it makes sense to use this approach rather than looking solely at the impact on absolute peak load.

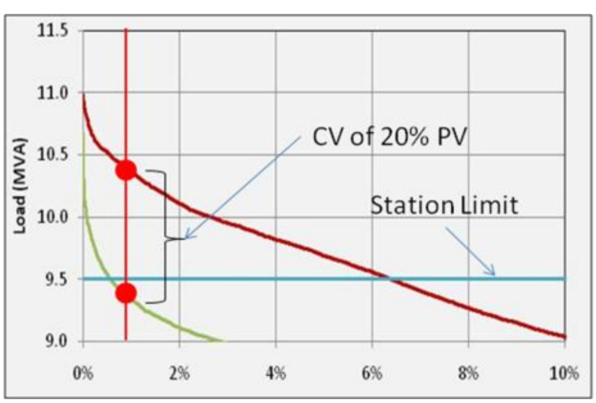

Figure 5 – Load Duration Curve with PV (green) and without PV (red). The horizontal axis is percent of the time over a one year period.

Further analysis to quantify the deferment value of PV is shown in Table 1 for a specific feeder and load. This table lists the projected growth (assumed to be 4%) of a substation load starting in 2009 and ending in 2016. In addition this table shows the number of hours that the load exceeds the substation rating and the peak load during the year. The net load is also shown for the substation with 10% (950 kW) PV and 20% (1.9 MW) of PV penetration on the substation. In 2013, the load exceeds the substation rating of 9.5 MVA for 17.5 hours. Adding 10% PV delays the overload condition for one year, possibly for two years. The 20% PV penetration delays the overload condition until 2015 or 2016 depending on the acceptability of a small number of hours in an over rating condition.

Year	No PV		10% PV		20% PV	
	Hrs >R	Peak Load	Hrs > R	Peak Load	Hrs > R	Peak Load
2009	0.0	8.4	0.0	8.2	0.0	8.1
2010	0.0	8.7	0.0	8.5	0.0	8.5
2011	0.0	9.1	0.0	8.8	0.0	8.8
2012	0.0	9.4	0.0	9.1	0.0	9.1
2013	17.5	9.8	0.0	9.5	0.0	9.5
2014	135.	10.2	3.8	9.9	0.3	9.9
2015	332.	10.6	61.0	10.3	7.5	10.3
2016	510.	11.0	179.	10.7	34.8	10.6

Table 1 – Example deferring substation upgrade using PV (R stands for substation rating)

The estimated deferral value is based on avoided cost of capital upgrades only. The paper will not attempt to compare cost-effectiveness of other alternatives to address the overload; however it attempts to provide enough information to allow for consideration of PV as options in the planning process.

ANALYSIS FOR DEFERRAL VALUE OF STORAGE AND PV

In cases where PV generation does not reduce the peak load sufficiently, adding energy storage could be considered as part of the solution. Some advantages of using PV with energy storage are PV generation reduces energy storage discharge time (energy drawn from storage), and can reduce Power Conditioning System (inverter) size requirements. The ideal synergy between the energy storage and PV generation takes place when PV deployment offsets load growth (Figure 6). This is because an energy storage system can be used to avoid overloads for multiple years. In addition to analyzing a PV only solution, the paper will provide some examples scenarios where energy storage may be effective. Analyses to determine a reasonable size of the energy storage will be discussed.

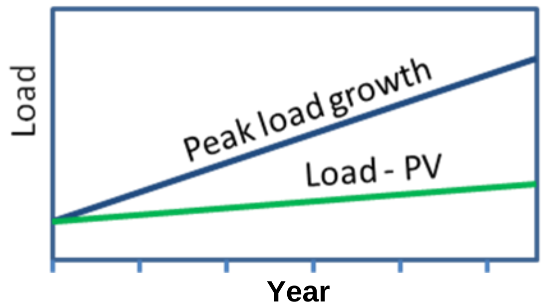

Figure 6 – Effect of PV deployment on load growth

Figure 7 shows the effect of adding energy storage to a substation. A reasonable energy management strategy would be to recharge the energy storage during off-peak outs, just after midnight in this example. The system with PV would be able to complete the charge process earlier because less energy is required from the storage system during the day. This means that a smaller energy storage capacity and a smaller grid interface (inverter) would be needed.

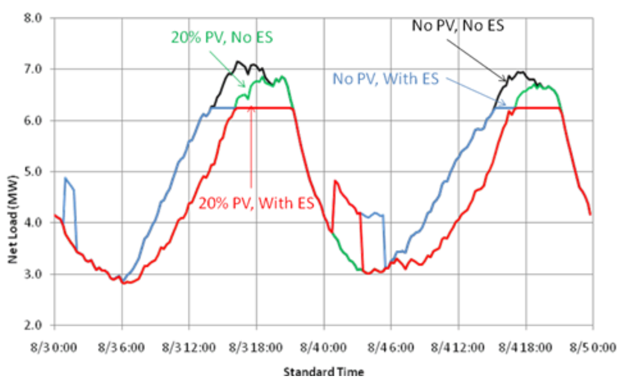

Figure 7 – Substation Load (black) with PV and Energy Storage (red), with PV (green), and Energy Storage (blue)

Technical considerations for the energy storage include the capacity (kW) of the power conditioning system, useful energy storage capacity (kWh), the energy storage technology available and portability if the storage is to be moved to another location after the deferment period. In addition, operating strategy and locations for the energy storage must also be considered. Another consideration is that the deferral horizon for storage is optimal for a 1-2 year period. This avoids the possibility of underutilizing energy storage capacity and makes a strong case for a mobile storage system.

The paper will describe the methodology was as applied to two test cases, a substation serving commercial load and a substation serving residential load. The basic results of these two cases are shown in Table 2. For both cases, the size of the required energy storage and the size of the power conditioning systems are reduced. With the commercial load, the reductions are larger than the residential case because the commercial load profile peaked earlier in the day (compared to the residential load profile) when the solar resource was much better.

Case	Energy (MW-h)		PCS Rating (MW)	
	No PV	20% PV	No PV	20% PV
Commercial	12.0	2.0	1.2	0.3
Residential	4.5	2.5	1.0	0.8

Table 2 – Example deferring substation upgrade using PV with Storage

Energy storage can cost-effectively defer upgrades over a couple of years. The deferral value is based on avoided cost of capital upgrades only. Energy storage is likely to be a utility-owned asset; thus it could be treated as an option among other alternatives. Other value opportunities should be considered in a full evaluation (voltage support, etc). These value streams have a lesser impact on station deferral, but can significantly improve the value proposition for a utility.

MONETIZING DEFERMENT VALUE

In order to compare deferment to upgrade alternatives, it is useful to monetize the deferral period. Deferment value is considered to be equivalent to the annual fixed charge rate multiplied by upgrade cost. Utilities earn a rate of return to cover the cost of equipment in service. The annual revenue requirement ranges from 8% to 15% of equipment costs, which reflects principal, interest, dividend, taxes, and insurance. An example calculation is as follows:

A 12 MVA station transformer is upgraded with a new 16 MVA unit for a cost of $1,200,000. Assume that the annual fixed charge rate is 11%, and that there is no residual value.

– The annual cost to own the new transformer is
  0.11 X $1,200,000 = $132,000
– The deferral value for 1 year is also $132,000
– In this case, the marginal cost of the T&D upgrade is
  $1,200,000 / 4 MVA = $300,000 per MVA

ACKNOWLEDGEMENT

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. This work is being conducted by Sandia National Laboratories funded by the Market Transformation Subprogram of the DOE Solar Program.

Rocky Mountain Power assisted in this study by providing circuit and load information that was used in the technical analysis.

REFRENCES

[1] SAND2010-0815, "Energy Storage for the Electricity Grid, Benefits and Market Potential Assessment Guide", 2010

[2] Hoff, Thomas E., et al, "The Value of Distributed Photovoltaics to Austin Energy and the City of Austin", 2006

[3] Data available from http://www.srrb.noaa.gov/isis/

[4] NREL/TP-560-34302, "Solar Position Algorithm for Solar Radiation Application", 2008

[5] SAND2004-3535, "Photovoltaic Array Performance Model ", 2004

[6] ABB Power Systems Inc., *formally Westinghouse Electric Corp*, "Electrical Transmission and Distribution [7] Reference Book" Section 5 – Power Transformers and Reactors, pp113-114.

[7] Tillman, Robert F. Jr, "The Electric Power Engineering Handbook", Section 3.11 – Loading Power Transformers, CRC Press and IEEE Press.