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Implications of Battery Storage for Solar Net-Metering Reforms

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***Abstract* — Compensation structures for residential solar PV are evolving toward a model that incentivizes the use of battery storage to maximize solar self-consumption. Using metered data from 1,800 residential customers across six U.S. utilities, we show that batteries operated solely in this manner often provide no grid value, due to misalignment with market prices. Incentivizing customers to discharge storage in response to market prices, particularly on infrequent peak load days would greatly enhance storage dispatch value. However, doing so requires consideration of local distribution network impacts. We illustrate a net billing design that yields a storage dispatch value equal to 50-70% of its maximum potential market value, without materially degrading solar self-consumption levels or increasing local grid stress.**

I. Introduction

Historically, the predominant compensation structure for distributed solar PV in the United States has been net metering, which credits all exported generation at the full retail electricity price. This has become a significant source of contention in many states, as utilities and others have raised concerns that net metering fails to recover fixed utility infrastructure costs borne to serve solar customers, and as a result tends to shift those costs onto non-solar customers [1].

In response, many states are considering transitions away from net metering, often to a “net billing” structure that provides lower levels of compensation for grid exports, while continuing to allow solar PV customers to directly offset their own usage contemporaneously [2]. The defining feature of this approach is its *asymmetric pricing structure*, with higher (retail) prices paid for solar PV that directly serves onsite load and lower (grid export) prices for solar PV exported to the grid.

Simultaneous with these compensation reforms, increasing numbers of residential customers are installing battery storage alongside solar PV [3]. Those trends have been spurred in large part by declining battery costs and rising demand for backup power. However, battery storage is also ideally suited to managing solar PV grid exports under net billing structures. In effect, customers can use storage to arbitrage between retail and grid export prices, thereby retaining retail rate compensation for much of their PV production, similar to net metering.

But does this arbitrage behavior provide commensurate value to the electric system? If not, then PV customers’ use of storage will ultimately undermine the intended objective of net metering reforms, raising the spectre of prolonging the contentious debates around distributed PV compensation.

This paper evaluates the aforementioned question through an empirical approach relying on historical hourly load from a diverse sample of residential customers across six U.S. utility service territories, paired with wholesale electricity market pricing data for the corresponding locations and time periods. We model the energy+capacity value of storage when dispatched in response to net billing pricing structures and compare to the maximum potential value if it were instead dispatched directly against energy and capacity market prices.

II. Data and Methods

The analysis relies on three sets of time-series data: (1) *Load Data*, consisting of metered hourly interval load data collected from roughly 1,800 residential customers without PV or storage, located in six utility service territories, over the period from 2012-2013; (2) *Solar production profiles*, generated using the National Renewable Energy Laboratory’s System Advisor Model, for the same locations and time periods as the load data; and (3) *Wholesale market price data*, consisting of day-ahead energy market prices and balancing authority system loads for the same locations and time period as the load data.

TABLE I
BATTERY DISPATCH SCENARIOS

Scenario		Consumption Price	Grid Export Price
1	Net billing with time-invariant pricing	Annual average retail price	Annual average solar market value
2	Net billing with hourly pricing, but no grid charging or discharging allowed	Hourly energy + capacity + T&D adder	Hourly energy + capacity
3	+ Grid charging allowed	Same as above	Same as above
4	+ Limited grid discharging allowed	Same as above	Same as above
5	+ Unlimited grid discharging allowed	Same as above	Same as above
6	- T&D adder	Hourly energy + capacity	Same as above

Using these data, we simulate storage dispatch and compute the market value of the resulting dispatch profile for each customer, across the series of scenarios outlined in Table 1. The scenarios progress in a step-wise fashion from net billing with time-invariant pricing in Scenario 1 to full market-based dispatch in Scenario 6. As the first intermediate step between those bookends, flat pricing is replaced with hourly varying pricing in Scenario 2, but consumption and export prices remain asymmetrical due to the the volumetric T&D adder included in

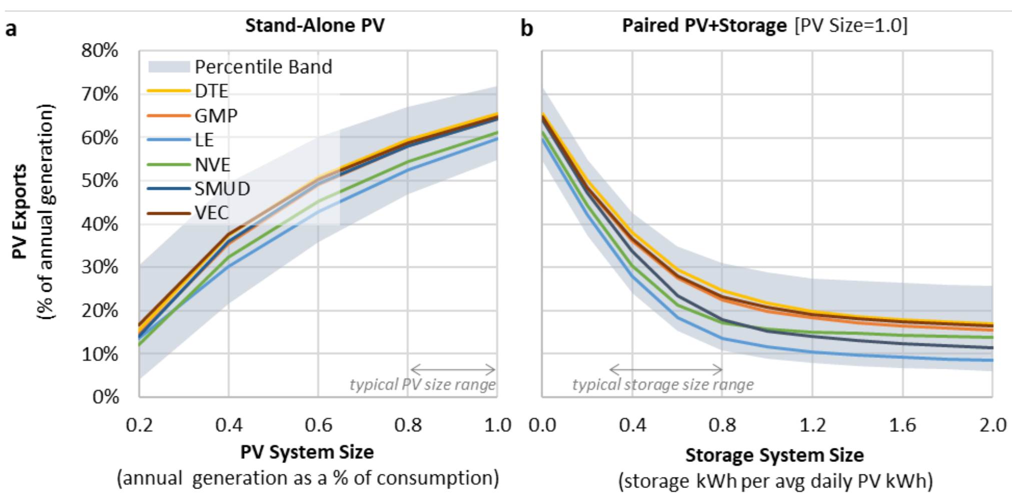

Fig. 1. Solar PV Grid Exports with and without Battery Storage. *Utility abbreviations: Detroit Edison (DTE), Green Mountain Power (GMP), Lakeland Electric (LE), Nevada Energy (NVE), Sacramento Municipal Utilities District (SMUD), and Vermont Electric Cooperative (VEC).*

the consumption price. Next, the limits on grid charging and discharging are sequentially relaxed in Scenarios 3-5. "Limited grid charging" in Scenario 4 refers to a case where the combined hourly exports from PV+storage are limited to the PV nameplate capacity, as is sometimes stipulated in interconnection agreements. Finally in Scenario 6, the T&D adder is removed, resulting in symmetric hourly prices for both consumption and exports. This is equivalent to the price signal faced by storage connected in front of the customer meter, responding directly to wholesale market prices.

In each scenario, storage is dispatched to maximize customer bill savings under the specified set of tariff prices and constraints. PV and storage system sizes are stipulated for each customer based on typical sizes currently observed in the market, with the base-case PV sized to generate 100% of the customer's annual consumption and storage sized at 50% of average daily PV production.

III. Results

Before delving into the market value analysis, Fig. 1 first shows how PV export levels vary with system sizing, and how increasing amounts of battery storage can reduce those export levels. As shown in Fig. 1a, PV systems within a typical size range and without storage generally export roughly 50-75% of annual PV generation over the course of the year. Storage operated to maximize self-consumption of solar PV can reduce export to roughly 10-30% of annual PV generation, for storage systems at the upper end of sizes typically observed in the market today. Larger batteries reduce exports further, but with diminishing returns, as a result of limits on the amount of nighttime load to serve with stored solar energy. Notably, these results are highly consistent across all six utilities.

Fig. 2 compares the market value of the storage dispatch profile under each scenario for each utility. The values plotted in the bar charts are the averages across all customers in the sample for each utility, and are disaggregated into the energy and capacity components.

The market value of the storage dispatch profile under net billing with flat rates (Scenario 1) is approximately zero across all utilities. This reflects the poor alignment between the times of storage charging and discharging and the times when energy and capacity prices are lowest or highest, respectively. This compares to a maximum potential market value of roughly $15-30 per kWh of storage capacity, annually, if storage were dispatched directly against market prices in Scenario 6.

Replacing flat prices with hourly varying prices in Scenario 2, but prohibiting grid charging or discharging with storage, increases storage dispatch value only negligibly. A much more significant jump in market value occurs in Scenario 4 where storage is allowed to discharge to the grid, albeit with limits based on nameplate PV capacity. Much of that jump is associated specifically with capacity value, which is concentrated in a relatively small number of high-priced hours each year. Depending on the utility, storage dispatch value under Scenario 4 equalas roughly 50-70% of its maximum potential market value. Notably, fully relieving grid discharge constraints in Scenario 5 has negligible incremental impacts on dispatch value, indicating that the discharge constraints in Scenario 4 are rarely binding during high-priced hours.

Finally, removing the fixed T&D adder on consumption prices in Scenario 6 eliminates the asymmetry between consumption and export prices, thereby fully aligning storage dispatch with market value. The value gap between Scenarios 5 and 6 is, effectively, a measure of the inefficiency attributable directly to assymetric pricing, and depending on the utility, equates to roughly 20-50% of the potential market value. The underyling source of that gap is that the fixed T&D adder tends to suppress routine daily arbitrage that would otherwise occur in response to diurnal variation in energy market prices.

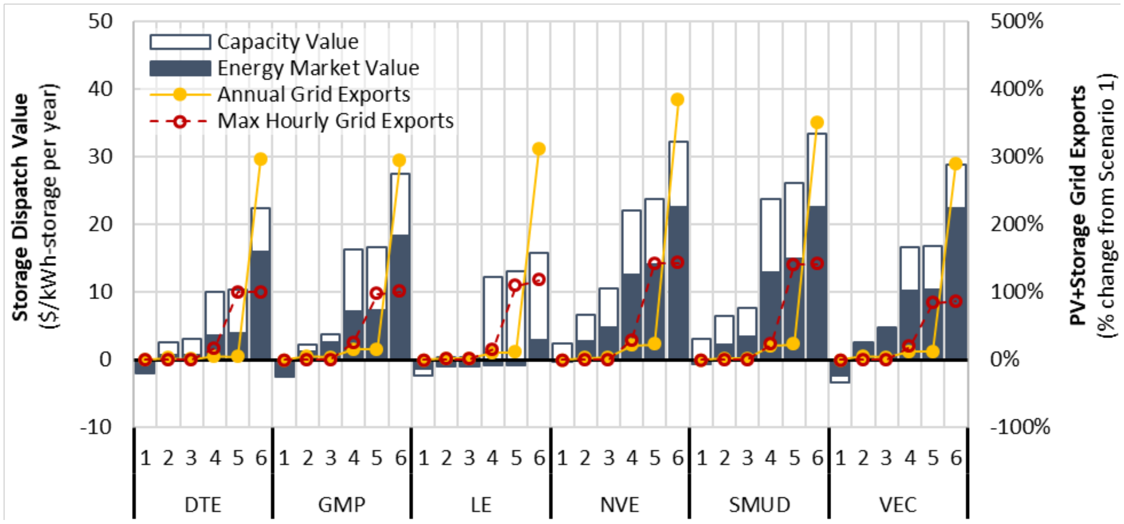

Fig. 2. Storage Dispatch Value and Grid Exports under Sequential Tariff Scenarios.

In addition to the dispatch value, Fig. 2 also shows both the annual and maximum hourly grid exports under each tariff scenario, presented as a percent change from Scenario 1. Two notable findings emerge. First, the maximum hourly grid exports increase dramatically from Scenarios 4 to 5, when grid discharge limits are fully lifted, yet market value is largely unchanged between those two scenarios. This is significant, because large amounts of instantaneous exports could create stress on the local distribution network. Scenario 4 thus represents a potential "sweet spot", insofar as it induces storage dispatch that realizes a significant portion of market value, without severely stressing the local network.

The second key finding related to grid exports is that annual grid exports remain virtually flat until Scenario 6. Removing the asymmetry between consumption and export prices in scenario 6 incentivizes a large volume of relatively low value (though still economical) grid exports.

IV. Conclusions

The most basic take-away from this analysis is that net billing is suboptimal from the utility system perspective, in terms of encouraging customers to operate storage in a manner that benefits the grid; however, the degree of suboptimality can be managed through rate design and interconnection rules.

Under many circumstances—particuarly with time-invariant pricing—battery storage dispatched in response to net billing structures yields virtually no market value. The implications of this are three-fold. First, it suggests the potential for significant deadweight loss, if PV customers make large capital outlays for storage equipment solely or primarily for the purpose of arbitrage between retail and grid export prices. Second, battery storage could undermine the intent of net-metering reforms: moving solar grid exports back behind the meter maintains the same sales and revenue erosion issues as with net-metering reform, but potentially without providing any commensurate cost savings for utility ratepayers. Third, net billing structures could perpetuate some of the same inequities that have been leveled at net metering, insofar as wealthier customers will be better positioned to purchase the storage equipment necessary to capture the net billing arbitrage opportunity.

The above notwithstanding, the results show how these issues can be mitigated through well-designed net billing tariffs. Most important is to ensure that customers with PV and storage are incentivized, allowed, and capable of discharging storage to the grid during the highest value hours over the year, which typically coincides to times of peak demand. Doing so, however, may create stress on local distribution systems, if large numbers of customers on a single circuit are discharging to the grid in unison. It is therefore essential to consider those potential impacts when developing tariff reforms for net metering, given the increasing prevalence of paired PV and storage.

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