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Maximizing Revenue from Electrical Energy Storage Paired with Community Solar Projects in NYISO Markets

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ABSTRACT

The New York State Public Service Commission recently made significant changes to the compensation mechanisms for distributed energy resources, such as solar generation. The new mechanisms, called the Value of Distributed Energy Resources (VDER), alter the value proposition of potential installations. In particular, multiple time-of-generation based pricing alternatives were established, which could lead to potential benefits from pairing energy storage systems with solar installations. This paper presents the calculations to maximize revenue from a solar photovoltaic and energy storage system installation operating under the VDER pricing structures. Two systems in two different zones within the New York Independent System Operator area were modeled. The impact of AC versus DC energy storage system interconnections with solar generation resources was also explored. The results show that energy storage systems could generate significant revenue depending on the pricing alternative being targeted and the zone selected for the project.

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ACRONYMS AND DEFINITIONS

Abbreviation	Definition
ESS	Energy Storage System
PV	Photovoltaic
NYISO	New York Independent System Operator
VDER	Value of Distributed Energy Resources program
CDG	Community Distributed Generation
LBMP	Locational Based Market Price
E	Environmental Value
DRV	Demand Reduction Value
LSRV	Locational System Relief Value
iCap	Capacity Value
SCC	Social Cost of Carbon
CC	Community Credit
MTC	Market Transition Credit
ITC	Investment Tax Credit
SAM	System Advisor Model

1. INTRODUCTION

As part of New York State's updates to their energy strategy, Reforming the Energy Vision, changes to the compensation of distributed energy resources have been put into effect. This has included a departure from simple net metering in an attempt to properly value *when* and *where* electricity is generated on the grid. The new mechanisms, called the Value of Distributed Energy Resources (VDER), includes multiple pricing alternatives for renewable power generators. The "value stack" for a distributed generator has six major components that vary regionally, with time-of-generation, etc. for community solar projects of 5MW or less [1]–[3].

Energy storage systems (ESSs) can be utilized to obtain additional revenue from a solar generation facility by optimizing the time that energy is sold to the grid. To properly estimate the revenue potential projects, the dispatch schedule that maximizes profits within the given pricing structure needs to be known. Previous work has investigated the potential of ESSs in various market areas and under different pricing structures such as time-of-use energy cost and net-metering scenarios [4]–[6]. Here, we present a method to determine the revenue that an ESS can add to community solar projects by taking advantage of time-of-generation pricing structures in the New York Independent System Operator (NYISO) area. Particularly, VDER values that are restricted to certain windows of generation or coincident peak hours can be captured more fully by adding ESSs to dispatch energy at the appropriate times if solar generation is not available or at its peak output. Additionally, as PV modules are generally oversized for the AC inverters, power that would normally be clipped by the inverter could be used to charge the ESS if the systems are DC-tied. In this way, additional energy can ultimately be dispatched while limiting the additional system cost by using the same inverter for the PV system and ESS.

To understand the maximum benefit that could be added with the use of energy storage, a comprehensive analysis that considers the local pricing structures and system configuration is needed. This paper presents a method to determine the maximum revenue that could be added with the use of an ESS by optimizing the dispatch schedule. The problem is formulated as a linear program and is solved using open-source tools. This method is applied to sample community distributed generation (CDG) projects in different service areas within the NYISO market area. The revenue from an ESS in AC-tied and DC-tied configurations is also assessed to highlight the optimal configuration for different applications.

2. ENERGY STORAGE REVENUE PROPOSITIONS UNDER THE VDER PROGRAM IN NY

The VDER value structures are continually being updated and modified in an attempt to encourage the installation of new generation assets that provide timely power to maximize the benefits to the network. To understand the revenue that could be obtained with a new project, the current rules and pricing structures need to be well understood. The most recent major change to the VDER program occurred on April 18, 2019 and implemented a number of updates to the program that have significant implications on the revenue from an ESS in particular. Though specific prices vary regionally, the basic value stack consists of six components [7]:

2.1. Energy

All energy produced is compensated for at the day-ahead hourly Locational Based Market Prices (LBMPs) set in the NYISO market for each node [8].

2.2. Capacity Value (iCap)

The capacity value is intended to assign value to generation that is provided during system peak hours. This value has multiple operating alternatives that can be selected, and each has a different revenue potential for ESSs.

2.2.1. Alternative 1

Under iCap-1, generators are paid a fixed, monthly rate for all energy delivered to the grid. The rate is essentially calculated from monthly NYISO clearing prices and estimated solar generation from 2:00PM to 7:00pm, which is the most likely window for peak loads in NYISO. With this option, extra revenue can only be obtained with an ESS if it is DC-tied to the PV system to deliver clipped energy.

2.2.2. Alternative 2

Under iCap-2, money is earned for generation 2:00 to 7:00PM June 24 – August 31 on non-holiday weekdays. Though this value is only available for ~240 hours of the year, the rate is generally much higher than the alternative 1 rate, making it a worthwhile option. An ESS can be very effective in this alternative structure as solar generation is generally low or declining during much of the active window.

2.2.3. Alternative 3

Under iCap-3, generators are paid on a $/kW basis for the power provided during the monthly coincident peak hour in the service area. The potential revenue from an ESS in this scenario is high as monthly coincident peaks generally occur between the hours of 4:00PM and 8:00 pm.

2.3. Environmental Value (E)

This value is a fixed $/kWh rate related to the diversion of the "Social Cost of Carbon" (SCC) with renewable generation. The current SCC rate as calculated by the New York State Department of Public Service is $27.41/MWh.

2.4. Demand Reduction Value (DRV)

Previously, this value was applied retroactively based on generation during the 10 peak hours throughout the year. The recent order changes this to generation during a known window of peak hours (2:00 to 7:00PM, June 24 -Sept 15 in most areas), to improve the certainty of revenue for generators. Rates are fixed over the first 10 years of the project.

2.5. Locational System Relief Value (LSRV)

This value is made available in particular areas where additional generation capacity is needed. Previously, this was paid similarly to the DRV as a retroactive payment for generation during the utilities 10 peak hours for the year. To ensure that revenue can be generated consistently, the new order has changed to a system in which utilities will send out a minimum of 10 calls for generation throughout the year with a minimum of 21 hours of notice. Revenue is then gained for the minimum hourly kW injection during the call window (1-4 hours).

2.6. Community Credit (CC)

This credit is available to community distributed generation (CDG) projects in certain areas as a fixed value for all generation for the first 25 years of the project. The available capacity for this credit is limited in each area, and prices change with location as well. Previously, this credit (formerly the market transition credit or MTC) was not available in combination with the DRV, but the recent order changed this.

Of the six value streams, the iCap, DRV, and LSRV in particular have positive implications for the addition of an energy storage system given the timing constraints on those values. In general, the applicable time frames are late in the day when solar generation is not available, or generation needs to be provided on demand, which photovoltaic systems cannot do on their own. As such, the potential revenue of energy storage paired with solar generation, particularly in areas with available LSRV capacity, could be significant if dispatched appropriately. Additionally, as most solar projects use DC to AC ratios greater than 1, if the ESS is DC-tied, energy that would otherwise be curtailed at the inverter could be used to charge the ESS and ultimately increase the output of the system.

3. MODELING AND OPTIMIZATION

3.1. Project Overview

Two potential projects were considered. The projects were selected to be in different service areas and of different PV system sizes. The configurations of the two projects are shown in Table 1. The fixed VDER values for each area are also listed. Capacity values change month to month in each area as will be discussed later in the paper.

Table 1: Proposed CDG Projects

	A	B
MW DC	7.5	3.0
MW AC	5	2
Fixed VDER Values (2018)		
E - $/kWh	0.02741	0.02741
DRV - $/kWh	0.01765	0.00417
LSRV - $/kW	2.56	N/A

Both systems are modeled to have a DC-AC ratio of approximately 1.5. Modules and inverters were selected from NREL's System Advisor Model (SAM) database to match the criteria specified and yield the specified AC and DC power ratings [9]. Solar generation was modeled using Sandia's PVLib model and specific inverter and module parameters from the SAM [9], [10].

3.2. Energy Storage Model and Optimization

For each proposed project, the charge/discharge schedule of a range of ESSs was optimized to maximize the revenue by solving a linear program using Pyomo in Python. This optimization was performed subject to the constraints on the system (battery state of charge, interconnection limits, etc.) as shown below:

$$\begin{aligned}
\max_{P_C, P_D, P_{curtail}} \quad & \sum_{t=1}^{T} P_{out,t} \cdot \left(iCap_t + DRV_t + LSRV_t + E + CC + LBMP_t \right) \\
where \quad & iCap_t = iCap_{price,t} \cdot iCap_{hour,t} \\
& DRV_t = DRV_{price,t} \cdot DRV_{hour,t} \\
& LSRV_t = LSRV_{price,t} \cdot LSRV_{hour,t} \\
subject\ to \quad & SOC_t = SOC_{t-1}\eta_s + \Delta t \left(P_{C,t-1}\eta_C - P_{D,t-1} \right) \\
& P_{out,t} = \eta_{inv} \left(P_{DC,t} + P_{D,t} - P_{C,t} - P_{curtail,t} \right) \\
& P_D \le P_{sys} \\
& P_{out,t} \le P_{sys} \\
& P_{C,t} \le P_{DC,t} - P_{AC,t}
\end{aligned}$$

* MERGEFORMAT (1)

Where P denotes power in kW, SOC state-of-charge, subscript *hour* indicates a binary array with a 1 for each hour corresponding to an hour in which the given VDER price is in effect, and subscripts *DC*, *AC*, *C*, and *D* represent solar DC, solar AC, ESS discharge, and ESS charge, respectively. In the case where the battery is only charged from clipped DC power, the power used to charge the battery, P_C, cannot exceed the difference between the DC power and AC power (inverter output).

Additionally, P_C can only be positive if the inverter power is at its maximum, meaning that any additional power would be curtailed. Alternatively, the battery could be allowed to charge from the full range of available power (AC or DC depending on the point of connection), making the final constraint in Eqn. * MERGEFORMAT (2):

$$P_{C,t} \leq P_{DC,t} \quad or \quad P_{C,t} \leq P_{AC,t} \qquad \text{* MERGEFORMAT (3)}$$

As a note, additional revenue could be generated with an ESS if it were allowed to buy energy directly from the grid. However, in many areas, NY included, energy for charging the system needs to come from a renewable energy resource specifically to qualify for investment tax credits (ITCs). Generally, the value of the ITC is significantly more than the additional revenue potential, so purchases directly from the grid were not be considered here.

Optimization is performed on a monthly basis, with the added condition that the battery begin and end the month at 50% state of charge. The algorithm assumes perfect foreknowledge of the pricing and demand in the system. Therefore, the results that follow represent the upper bound of possible revenue that could be obtained with an ESS. It was also assumed that 25% of the battery's energy would be kept in reserve, which would improve the longevity of the system and give some margin for operational inefficiencies that are not directly modeled. Note that for this analysis, the self-discharge, η_s, efficiency and roundtrip efficiency, η_c, were assumed to be 100% and 85%, respectively. The inverter efficiency was assumed to be 94%. The linear program was implemented in Python using Pyomo and solved using the GNU Linear Programming Kit [11]–[13].

4. RESULTS AND DISCUSSION

The results presented in this section show the additional annual revenue for the proposed projects that could be obtained by coupling the PV generation with an ESS. For comparison, results will be shown in a case where the batteries are DC-tied, charging from either clipped energy only or from the full range of available power, and AC-tied. This will show the potential benefit of each configuration. For each configuration, a range of battery sizes are optimized to give a sense of where diminishing returns with increasing battery size occur. The range tested is from approximately 15 minutes to 4 hours of full rated discharge. For the following analyses, we use historical VDER rates from 2017, shown in Table 2. Also, the LSRV calls are modeled as 1-hour calls occurring at the same times as the 10 system peak hours for each area in 2017.

Table 2: Historical iCap alternative monthly prices 2017

	A		B	
iCap	2 ($/kWh)	3 ($/kW)	2 ($/kWh)	3 ($/kW)
Jan	$ -	$ 0.27	$ -	$ 3.40
Feb	$ -	$ 0.27	$ -	$ 3.26
Mar	$ -	$ 0.16	$ -	$ 3.26
Apr	$ -	$ 0.11	$ -	$ 3.34
May	$ -	$ 2.05	$ -	$ 3.13
Jun	$ 0.08	$ 2.81	$ 0.25	$ 4.67
Jul	$ 0.08	$ 3.78	$ 0.25	$ 11.54
Aug	$ 0.08	$ 4.03	$ 0.25	$ 11.45
Sep	$ -	$ 3.51	$ -	$ 10.82
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

4.1. General ESS Dispatch Schedule

Again, the most substantial revenue streams with an ESS come from the iCap, DRV, and LSRV values. Generally, to optimize the revenue from an ESS operating under iCap-2, the battery should be fully charged before the iCap/DRV window begins and discharge fully for as long as possible once the window starts, as shown in Figure 1.

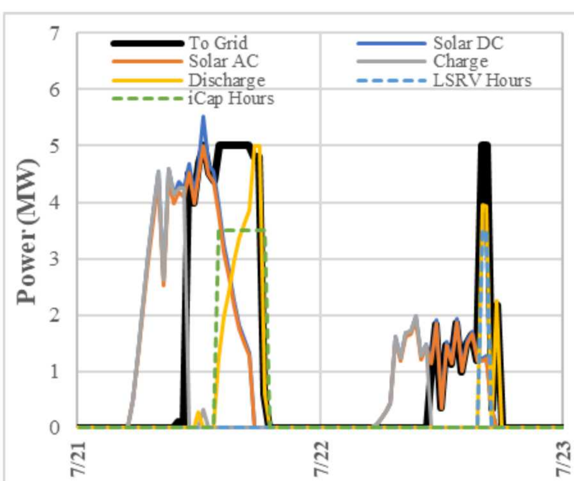

Figure 1: Project A sample ESS dispatch schedule - 20 MWh ESS capacity

As such, multiple hours of energy storage are necessary to maximize the potential revenue given the length of the iCap/DRV window during the applicable months. Batteries also help to address the LSRV calls, during which the PV output is generally fairly low.

4.2. Project A (7.5 DC / 5 AC MW)

First, the revenue that could be generated with an ESS in Project A is shown. In this case, the power rating of the shared inverter for the PV/ES system is already at the transmission limit for CDG projects (5 MW). As such, there is no potential benefit to having a dedicated ESS inverter as the limit of the PV inverter cannot be exceeded. The potential revenue for ESSs with different charging schemes is shown in Figure 2 and Figure 3. Besides the differences in charging schemes, there are also differences in potential revenue based on the iCap alternative that is selected. Figure 2 shows the revenue that can be obtained under iCap-2 (2:00 to 7:00PM June 24 – August 31).

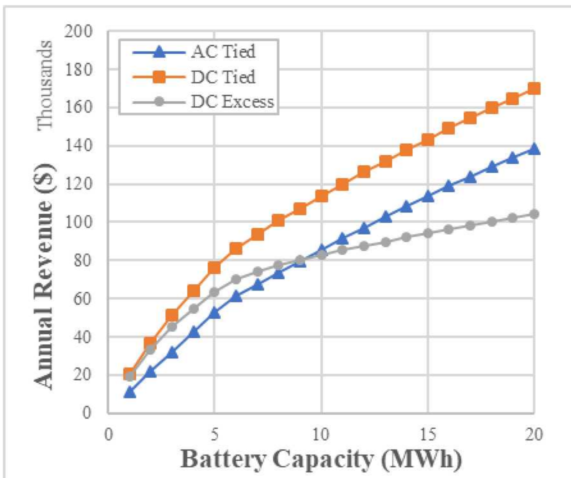

Figure 2: Project A added ESS value under iCap alternative 2

The system should also be configured so the ESS charges from the full range of available power. Since a significant amount of energy is required to discharge for the 5-hour window, potentially clipped DC energy alone is insufficient to maximize the benefit of an ESS. When charging from all available power, direct access to the DC generation from the PV system increases the revenue that can be added with a battery by approximately 41% as compared to an AC-tied configuration.

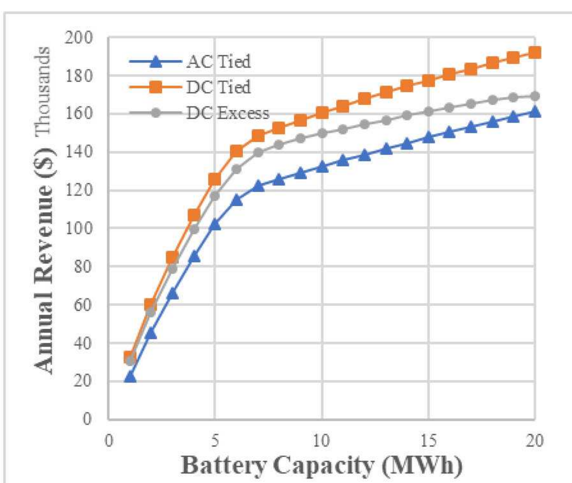

Figure 3: Project A added ESS value under iCap alternative 3

Alternative 3 leads to even higher potential revenues, as shown in Figure 3, because the $/kW-month rates under this option are generally high during the summer months (Table 2). Furthermore, high returns can be reached with relatively small ESS capacities as the necessary window of operation is only 1 hour per month. If the duration of the ESS at maximum rated power is increased beyond 1 hour, more revenue can be generated from maximizing revenue from LBMPs, but the additional revenue from increasing the storage capacity decreases.

4.3. Project B (3.0 DC / 2 AC MW)

4.3.1. Potential with a shared ESS/PV inverter

Project B differs from Project A in two major ways. Firstly, Project B is modeled in a different service area, that does not offer LSRV incentives, but has much higher iCap prices. Secondly, as this project's peak generation limit is well below the interconnection limit for CDG projects, it is unclear whether the maximum cost-benefit would occur by sharing an AC-DC inverter with the PV system.

First, we will look at the revenue with a shared AC-DC inverter as was done for Project A. Figures 4 and 5 show the potential revenue that could be gained under iCap alternatives 2 and 3, respectively. Again, alternative 2 is a higher energy application, and requires more energy than can be gained from clipped energy alone. This is particularly true for Project B, because there would be much less energy being curtailed at the inverter than at Project A given the relative size of the solar arrays. As a result, though the alternative 2 prices are about 3 times higher in Utility B than Utility A, the potential benefit of an ESS for Project B is relatively low given the lower energy of the system, as shown in Figure 4.

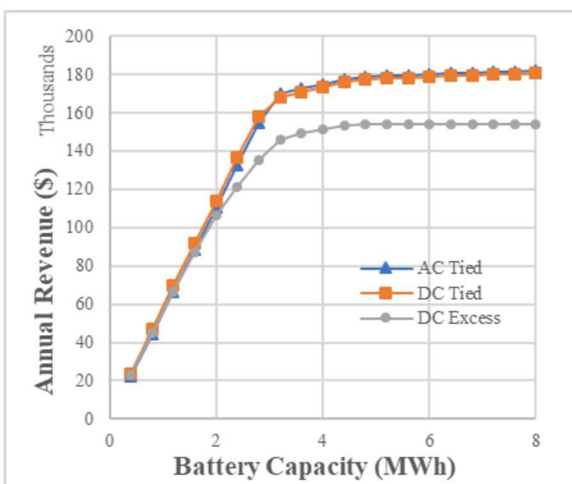

Figure 4: Project B added ESS value under iCap alternative 3 – shared inverter

However, performance under the iCap alternative 3 option has a higher earning potential for Project B than A despite the lower total energy production, as shown in Figure 5. This is because alternative 3 prices are approximately ten times higher in Utility B than in Utility A for many months of the year. Again charging from the full available range of power is essential to maximize the benefits and the peak revenue can be reached with a much smaller system given the low energy needs to discharge for the necessary hour each month.

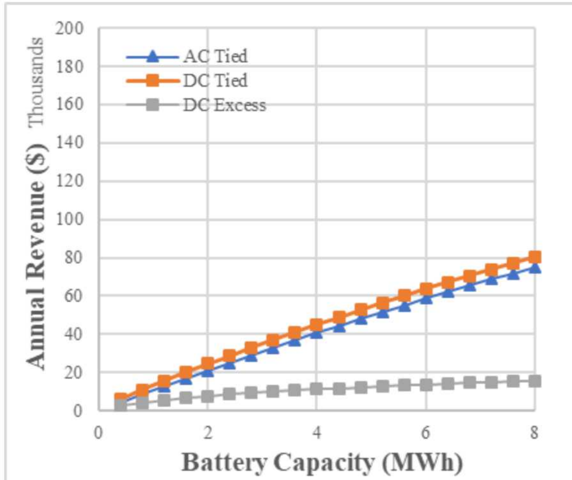

Figure 5: Project B added ESS value under iCap alternative 2 – shared inverter

4.3.2. Potential with a dedicated ESS inverter

Though DC connections clearly have the potential to deliver more power to the grid by capturing the excess energy that would be curtailed otherwise, if the AC-DC inverter of the PV is also shared, the maximum power that can be delivered to the grid is limited by the PV inverter size. In some cases, it may be beneficial to use a separate inverter for the battery to increase the potential power output during key times of the day.

For CDG projects in NY, the power output is limited to 5MW. As such, a dedicated ESS inverter provides no benefit for Project A. However, the PV system at Project B is well below the 5MW interconnection limit, so additional revenue could be gained from a dedicated ESS inverter such that the battery could discharge power above the PV inverter limit. This could be particularly beneficial under alternative 3 where a high rate of discharge for a limited amount of time has a high revenue potential.

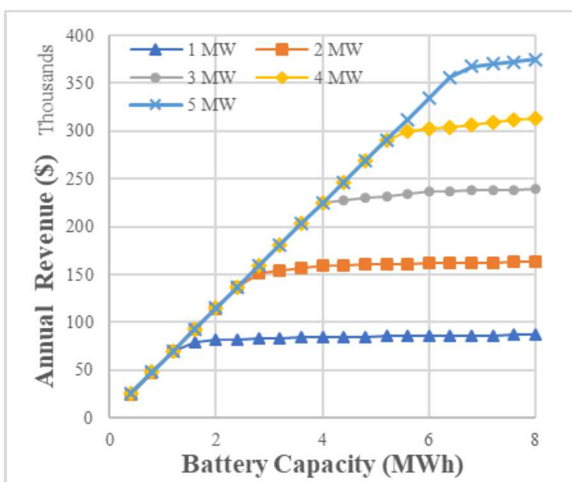

Figure 6: Project B added ESS value under iCap alternative 3 – dedicated ESS inverter

Figure 6 shows the revenue that an ESS could add to Project B with dedicated ESS inverters of increasing size rather than sharing an inverter with the PV system. Under iCap alternative 3, the maximum benefit of an ESS increases almost linearly with the inverter size, though larger ESSs capacities are needed to reach the maximum potential as the inverter power rating increases. This sort of configuration of course would increase the system cost. The additional cost of the dedicated inverter would need to be weighed against the additional revenue that could be earned over the project life to yield the optimum profit from the system.

5. CONCLUSIONS

The Value of Distributed Energy Resources program that has been implemented in NYISO seeks to value both *when* and *where* energy is generated to encourage projects that will be the most beneficial to the network. This pricing structure makes the addition of an energy storage system to PV installations an attractive option to maximize profits. Recent changes to the program have increased the revenue potential of dispatchable ESSs further as high value operating windows have shifted later in the day and utilities now send generation calls 21-hours in advance, likely at times when solar generation will be low. The recent changes also make the estimation of profits from proposed projects more straightforward by moving away from retroactive payments to more defined pricing windows and calls for generation with advanced notice.

To understand the revenue that could be generated with the addition of an ESS with the prevailing pricing structure, ESSs were modeled in conjunction with two hypothetical community solar projects in two different service areas. The AC and DC PV generation at the locations was modeled using the Sandia PVLib model and inverter/module information from the NREL SAM. Modeling the DC output as well allowed for representation of a DC-tied ESS that could charge from solar power that would otherwise be curtailed at the AC-DC inverter. A linear program to describe the solar and ESS systems was developed and solved using open-source tools.

The results of the analysis show that operating under capacity alternative 3, which incentivizes generation during the monthly system peak, is the highest revenue proposition for the addition of an ESS in the two service areas modeled. This would require accurate forecasting of the peak hour to maximize profits, but such efforts are possible and have been effectively utilized in some areas. Alternative 2, generation during peak load windows during the summer, can also have a high value in some cases, though longer duration storage systems are necessary. For both capacity alternative options, charging the ESS from the full range of DC solar generation led to the highest revenue as this provided enough energy to perform the optimal dispatch of the ESS.

Sizing and siting of ESSs needs to be carefully considered to maximize profits, particularly given the locational dependencies of value streams in NY. The method presented here gives an estimation of the maximum revenue that could be earned with an ESS in a community solar project in NY by optimizing dispatch with consideration of the various time-of-generation prices.

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