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Energy sharing through shared storage in net zero energy communities

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Energy sharing through shared storage in net zero energy communities

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Abstract. Growth in the adoption of distributed energy resources is shaping a new energy ecosystem posing a perceptible threat to the grid by relying on it as a virtually inexpensive storage mechanism. This growth is compounded by new policy objectives that require pursuing net zero energy (NZE) goals for new buildings. One emerging framework that attempts to remediate this problem is energy sharing in a community microgrid. In this framework, through complementary demand profiles and shared energy storage, buildings use energy resources more efficiently with the objective of reducing grid interactions. In this paper, we create a year-long discrete-time simulation model of 40 residential and non-residential buildings to measure the reduction in grid interactions through energy sharing and shared storage for the case of a NZE community. Our results show that, when sharing is enabled, a 9.5% reduction in grid interactions can be obtained with buildings that have energy storage. Additionally, a month-by-month exploration revealed that annual patterns in generation drastically impact the benefits from sharing energy. The reduction in grid utilization ranged from 20% during periods of high energy surplus (i.e. summer) to 5% during low energy generation (i.e. winter).

1. Introduction

1.1. Motivation

Recent reports in climate science continue to incentivize policymakers and governments to approve accelerated efforts for reducing CO_2 emissions in relatively short time frames [1]. These efforts are handled jointly with the knowledge of the rising urban population, which is expected to reach 68% by 2050 [2]. One common response from policymakers is to mandate net zero energy (NZE) objectives for new buildings after a specified date [3]. Although this is an intuitively practical solution, NZE only requires a null annual accounting of energy, which often overlooks the shorter time-scale energy export/import interactions with neighboring grids [4]. These energy interactions are defined as the amount of energy exchange with the bulk power grid in both directions [5]. Increased grid interactions from NZE buildings require reinforced grids and additional management solutions which burden the grid operator and/or customers [6]. One recent approach to minimize grid interactions is to look at the diversification of electrical energy demand profiles at an aggregated level (i.e. a community scale) [7]. These developments, coined as net zero energy communities (NZEC), have many expected value streams such as: cost benefits from economies of scale, balancing loads through energy sharing, and management of peak consumption and injection to the grid [8]. Given that high surplus generation is an inherent characteristic to the NZE objective, energy sharing can facilitate the exchange of that surplus aided by energy storage in the future design of NZECs.

1.2. Related Work
In recent years, there has been an increased interest in energy sharing of buildings due to the potential in reducing grid interactions [9–14]. A high volume of work targets the development of advanced algorithms focused on the frameworks through which energy sharing can occur. However, due to short simulation periods and lack of scenarios with realistic a number of buildings and building mix, several conclusions do not necessarily give insight to the feasibility of these projects. For example, in the work of [9], an energy sharing platform was created and tested in ten buildings, demonstrating a reduction in energy exchange with the grid up to 42% with high demand diversity. Using energy storage, [10] proposed a solution for energy management of four buildings who share their storage device. Similarly, [11] designed a two-stage battery control in a community microgrid to increase on-site energy utilization. This previous work additionally explored the impact of battery sizes in an energy sharing framework. In the context of NZE, fewer articles have been published. The authors of [12], with a clustering algorithm for collaboration of NZE buildings, concluded peak energy exchanges can be reduced by 16%. In the work of [13], three NZE buildings were modeled with collaborative controls reducing grid interaction. Finally, the authors of [14], published one of the only works performing a year-long simulation of a cooperative NZEC achieving high on-site energy utilization, although only five buildings were considered.

1.3. Research Objective
Based on previous works, we identify the three main contributions of this paper. First, our case study emulates a mixed-use development of 40 residential and non-residential buildings roughly corresponding to the size and makeup of the planned first phase of the Hazelwood Green development [15]. Hazelwood Green is a 72 hectares mixed-use brownfield site in Pittsburgh, Pennsylvania with high-achieving sustainability goals, including net zero energy. In choosing this development as a guideline, we address the need for modeling heterogeneous buildings at a district scale that are comparable to similar pilot districts presented in [8]. Second, we parametrically explore the effects of varying shared energy storage capacity and annual generation. Third, to account for the lack of longer period studies, we run our model for a year-long simulation to investigate the seasonal effects of variations in demand and generation. To address these three objectives, we design a discrete-time simulation model of a group of buildings equipped with on-site renewable generation and energy storage systems (ESS) to evaluate the annual reduction in grid interaction when energy sharing is enabled.

2. Simulation Setup
2.1. Demand and Generation Inputs
We use the Hazelwood Green development [15] to select the building mix and number of buildings for the simulation. The parameters assumed were selected according to the planned residential and non-residential space, as well as prior knowledge of the future use of the site. The building mix was created by selecting validated DOE Commercial Prototype Buildings [16], and simulating their load profiles at a 15min timestep using Energy Plus [17]. The building types included in this simulation are: medium office, small office, retail standalone, retail strip mall, restaurant, apartment high rise, and apartment mid rise. The final model has a 40% residential and 60% non-residential building mix by area composed of 40 buildings accounting for roughly the scale and makeup of the first phase of the development. To increase the load diversity, each building load profile was modified with a daily perturbation value and a timestep perturbation value as shown in [18], where the variability was set to 10%. The generation input for every building was obtained from the Solar Power Data for Integration Studies [19], with the closest location to the site and appropriate timestep.

2.2. Annual Generation and Battery Size

To explore the influence of generation in the simulation, we define the variable $AG_i \in [0,1]$ for a building i such that $AG_i = 0$ represents no annual generation and $AG_i = 1$ represents annual generation equal to annual consumption. Note that the upper limit of AG_i represents a building that has fulfilled the NZE definition. Similarly, to vary the size of the ESS, we define the variable $SC_i \in [0,1]$ such that $SC_i = 0$ represents no storage capacity and $SC_i = 1$ represents a storage capacity equal to the average daily energy consumption for building i.

2.3. Simulation Workflow

To begin, we create a reference scenario where each building operates with individual utilization of energy storage. No sharing of surplus energy is enabled, hence there is no information exchange between the buildings and the local aggregator. In essence, each ESS is charged when there is surplus generation and discharged when there is a deficit, following exclusively the limitations imposed by the battery specifications for each case. On the other hand, when energy sharing is enabled, a surplus/deficit of energy is met with a linear charging/discharging of all available batteries based on their respective nominal capacity and the net power requirement of the community. This rule-based control was introduced by [11], where a local aggregator sends a signal to all users for charge or discharge depending on the net balance of the community for the respective timestep, allowing for energy sharing through storage. This mechanism, when information is perfectly shared, is equivalent to a community-shared energy storage with the same aggregated nominal capacity. Notice, that in the case when the buildings have no storage, both the reference and the sharing case will be the same because instantaneous supply and demand is met within the microgrid before the point of common coupling. That is to say, from the perspective of the grid, simultaneous exports and imports are not perceived. For the sake of simplicity, both AG_i and SC_i were considered to be the same for all buildings for every simulation scenario and can be referred to as AG and SC. The metric chosen to evaluate the effects of sharing is the *net grid interaction* (NGI) (from Equation 1). This index is a measure of grid utilization similar to the energy balance index introduced by [5]. For our case, this reflects energy exchanges between the community microgrid and the wide area interconnection. For comparison, we will calculate the change in NGI as described in Equation 2. A simplified simulation workflow is shown in Figure 1 for reference. First, we define a pair of AG and SC for a given simulation instance. The input SC is used to determine the size and properties of energy storage for each building. The properties of the ESS of every building were derived from scalable versions of the Tesla Powerpack 2. The nominal version of this battery model has an energy capacity of 210kWh and power rating of 50kW with a round-trip efficiency of 90% [20]. The input AG is used to determine the generation for the whole year by scaling the generation vector. With these model inputs, we simulate the reference and sharing scenarios for a specified time interval T. Then we can calculate the NGI value for both cases and use them to calculate ΔNGI. We repeat this workflow for different values of AG and SC.

$$NGI = \sum_{i=1}^{T} \mid exp(t) - imp(t) \mid \qquad (1)$$

$$\Delta NGI = 1 - \frac{NGI_{share}}{NGI_{ref}} \qquad (2)$$

3. Results and Discussions

3.1. Full Year Simulation

We constructed a simulation space using a large scale parametric sweep of 2500 (50 × 50) combinations of linearly discretized values of AG and SC for both the reference and sharing cases. The goal was to evaluate the reduction in grid interaction between the two cases using ΔNGI as explained previously. Figure 2 summarizes the results for a full year simulation displaying AG on the vertical axis and SC on the horizontal axis. Every pixel represents the

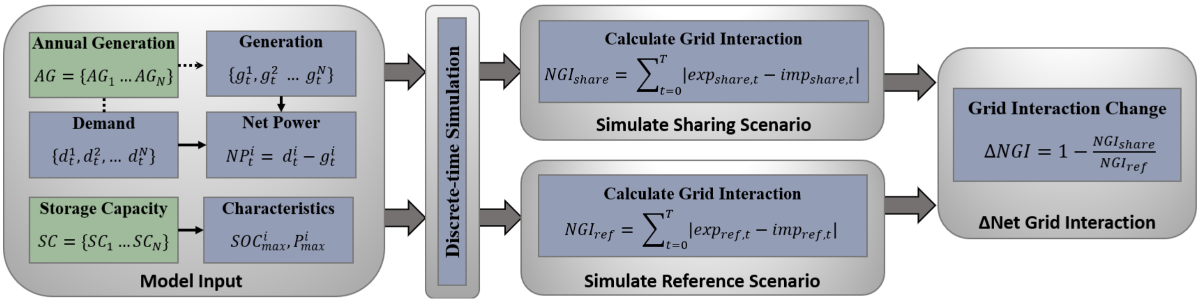

Figure 1. Simplified workflow of simulation for a given AG and SC

value of ΔNGI measured by the color bar at the right of the figure. A high value of ΔNGI means that the sharing scenario achieved a higher reduction in grid interaction compared to the reference case. As we can see from Figure 2, ΔNGI is minimal for values of $AG < 0.50$, regardless of the battery size. This supports the idea for studying NZE cases because sharing is enabled when surplus energy is available. From this figure, we can also see that the reduction in grid interaction is greatest for $0.30 < SC < 0.50$. Further looking at the charge/discharge patterns of the ESS of buildings, we find that when each building has a large battery, then it is able to use it individually much more effectively, therefore gaining less from energy exchanges. This implies that energy storage enhances energy sharing up to a capacity, regardless of annual generation, after which the magnitude of the enhancement is decreased. We can also see that in the case where $AG = 1$ (i.e. NZE) the maximum reduction in grid interaction of $\Delta NGI = 9.5\%$ occurs at $SC = 0.42$. Interestingly, the overall maximum reduction in grid interaction is $\Delta NGI = 11.4\%$ occurring at $SC = 0.40$ and $AG = 0.80$. This is explained by the fact that when a community operates at NZE very high grid injections occur that cannot be aided by sharing or storage. However, for lower levels of generation, the dynamics of sharing and storage are more effective in reducing grid interactions.

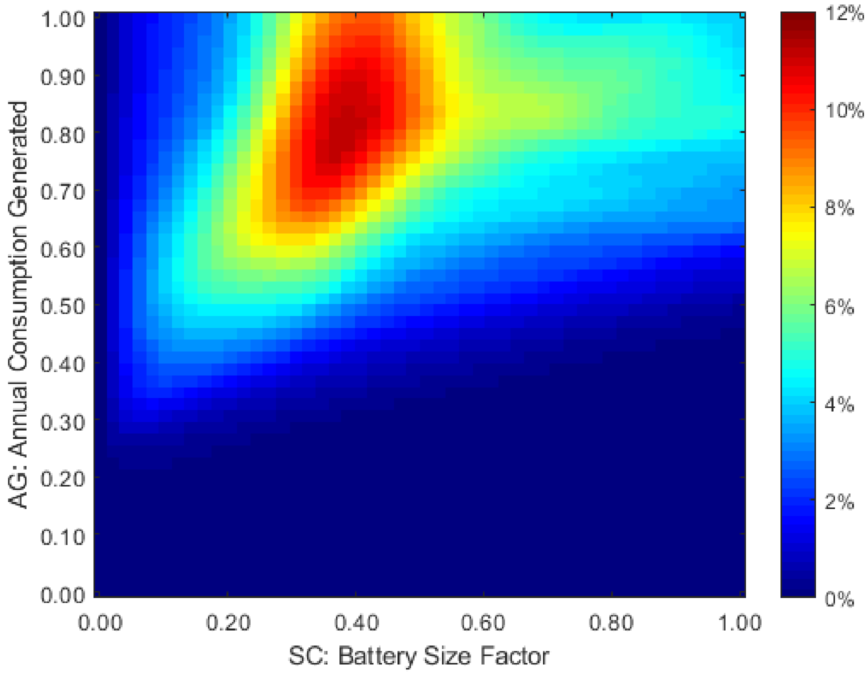

Figure 2. Heat map of full-year simulation displaying annual generation AG on the vertical axis, storage capacity SC on the horizontal axis and reduction in grid interaction ΔNGI as a colored pixel

3.2. Month-by-month Simulation
A similar analysis to Section 3.1 was done by creating monthly snapshots to capture the seasonal effects of generation and demand. Figure 3, using the same axes as Figure 2, shows a heat map for every month of the year. It is important to note the color bar has a different scale than that of Figure 2. As we can see from this figure, every month has a different potential given a specified energy storage configuration. However, for the special case of NZE, we can choose to explore the values of ΔNGI for which the year-long simulation has an optimal value, as shown in Section 3.1. As seen in Table 1, energy sharing offers significant reductions in grid interaction when there is surplus energy during the summer months, conversely, during the winter months, the values for ΔNGI are much lower. In terms of load cover factor, a common measure for evaluating NZE projects [6], we calculated an increase of 86.1% to 90.1% for the month of July (summer month) and an increase of 52.9% to 54.5% for the month of January (winter month).

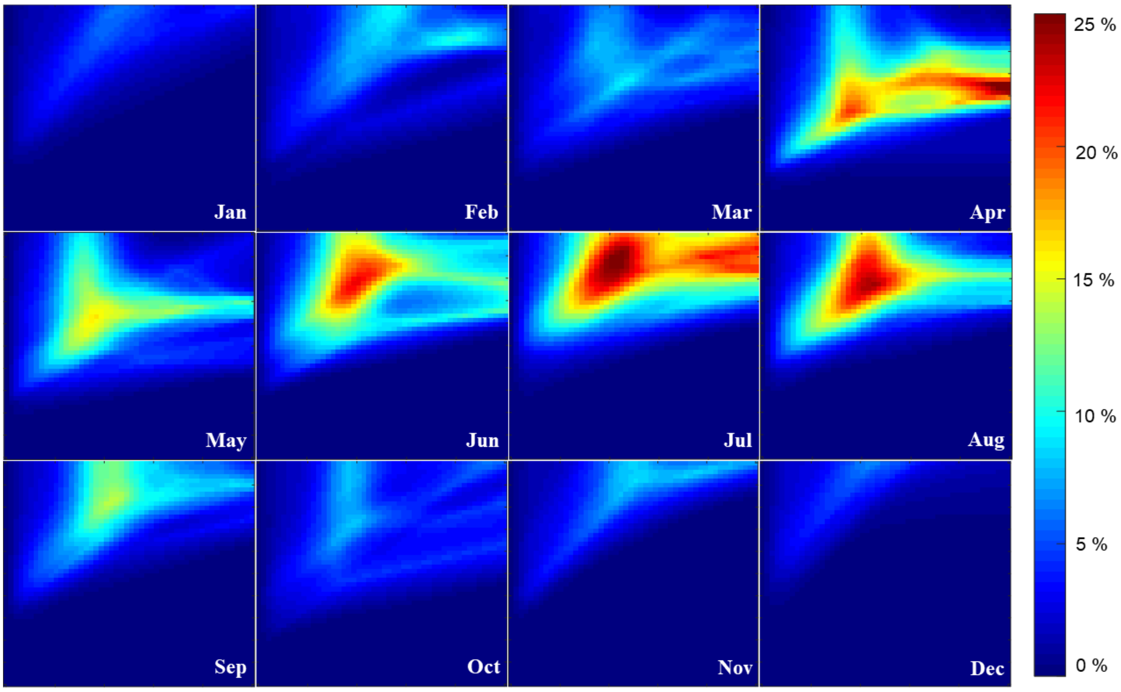

Figure 3. Monthly snapshot showing ΔNGI with axes similar to Figure 2 (Note different color bar scale than Figure 2)

Table 1. ΔNGI for $AG = 1.00$ and $SC = 0.42$ for every month of the year

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
5.4%	6.6%	6.5%	6.3%	6.2%	14.0%	20.1%	15.6%	12.1%	7.3%	6.7%	6.2%

4. Conclusions
In this work, we study the reduction in grid interaction from energy sharing through energy storage in a net zero energy community microgrid. Our simulation results indicate that energy sharing and shared storage in a NZEC setting has the potential for reduction in grid interactions of 9.5%. This result and our model can further provide insight into quantifying reduced operational costs from low grid feed-in tariffs and justification for investment of energy sharing frameworks in mixed-use developments. Through the parametric exploration of storage capacity, we find that energy storage capacity enhances energy sharing up to a certain extent ($SC = 0.42$ for our case) after which higher storage capacity might not be as effective. Moreover,

we find that most of the reduction in grid interaction happens during months of high generation ($\Delta NGI = 20\%$ in July). In contrast, during months of low generation, instances where surplus energy can be shared are rare ($\Delta NGI = 5\%$ in January). This result suggests the importance of future studies on energy sharing to simulate or test representative long periods of time to account for seasonal variations in demand and generation. For example, if a shorter high-generation period was selected, the reduction in grid interaction will be high, however it might not accurately portray of year-round operation. Regarding future research, we recognize that there is a need for a more techno-economic analysis in terms of optimal storage capacity and necessary infrastructure that more explicitly justifies the investment in this technology. Furthermore, additional research should explore more advanced algorithms to enable energy sharing that solve for objectives such as peak load management and cost reduction. Finally, extensive work is needed in studying the design of appropriate business models that would encourage investment, satisfy customers and ensure reduced operational costs.

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