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Adaptive Charging and Discharging Strategies for Smart Grid Energy Storage Systems

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Abstract. The current state of energy generation and consumption in the world, where many countries rely on fossil fuels to meet their energy demands, poses significant challenges in terms of energy security and environmental degradation. To address these challenges, the world is shifting towards renewable energy sources (RES), which are not only environmentally sustainable but also have the potential to reduce dependence on fossil fuels. However, the intermittency and seasonality of RES arise new challenges that must be addressed. To overcome these challenges, energy storage systems (ESS) are becoming increasingly important in ensuring stability in the energy mix and meeting the demands of the electrical grid. This paper introduces charging and discharging strategies of ESS, and presents an important application in terms of occupants' behavior and appliances, to maximize battery usage and reshape power plant energy consumption thereby making the energy system more efficient and sustainable.

Keywords: Adaptive charging, Energy storage systems, Smart Grid, Energy, Renewable energy sources, Simulation, Occupants' behavior model.

1. Introduction

Many countries in the world rely heavily on oil, coal, and natural gas to meet their energy demands [1]. However, this reliance on fossil fuels presents two significant challenges from a perspective of energy security. Firstly, the import of fossil resources is subject to significant price swings, which can negatively impact the stability of a country's economy and make it difficult to predict the situation in regions that import these resources. Secondly, the use of fossil fuels leads to environmental pollution and the emission of greenhouse gases, such as carbon dioxide (CO_2), which contribute to the global warming problem.

Growing energy demands and fossil fuels depletion together with COVID-19, after-pandemic times, and global energy crisis in 2021-2022 force modern world to switch energy generation from fossil sources to renewable energy sources (RES) [2, 3]. Renewable energy has great potential to reduce prices and dependence on fossil fuels in the short and long term. On the other side, intermittency and seasonality of renewable energy makes RES hard to use. Although costs for new photovoltaic panels (PV) and wind installations have increased [4].

Some regions and countries are starting to introduce RES, but the intermittency of renewable energy is still covered by peak power plants burning oil and natural gas. To fully switch to renewables the generated energy has to be stored and used when renewable resources are not available. In such a case it is hard to underestimate the importance of energy storage systems (ESS) for modern world and smart grid (SG) systems.

Typically, a private house connected to the utility power line through a battery would have a solar panel array installed on the roof or elsewhere in the property. The solar panels would convert sunlight into direct current (DC) electricity, which would then be fed into an inverter.

The inverter would convert the DC electricity into alternating current (AC) electricity, which is compatible with the utility power grid. Also the DC electricity generated by the solar panels would be sent to a battery storage system, where it would be stored for later use. The battery storage system would be connected to the utility power grid, allowing the house to draw electricity from the grid when the battery is depleted and feed excess electricity back into the grid when the battery is charged.

A control system would be used to manage the flow of electricity between the battery, the solar panels, and the utility grid. This control system would monitor the electricity demand of the house and adjust the flow of electricity accordingly.

On the other side, energy storage system can have different goals [5]. For example, energy storage can be used to make renewable energy output more stable for bringing it to a combined energy mix for large regions. ESS can be used for energy shifting to make electricity availability supply curve meet the electricity demand curve. Another use case is voltage and frequency regulation which is a typical issue in Smart Grids with many distributed renewable sources such as PV installed locally at residential houses and residential wind turbines, and which feed the energy back to the grid.

Charging and discharging strategy can be optimized to solve a specific goal: maximize battery usage to reduce power plant (fossil fuels) energy consumption, and based on statistical data and probabilities decide when to charge and when to discharge, such as charge when grid frequency goes up and discharge when frequency goes down.

This paper introduces adaptive charging and discharging strategies based on energy availability data and energy demand data. We propose a model which controls battery use based on consumption demand and selected charging/discharging strategy represented in the form of a function of battery internal state. In a very simple case the battery is always used or a threshold value is defined. A more advanced case takes into account energy storage efficiency factor, capacity, charging and discharging speeds, and other characteristics.

This paper is organized as follows: Related work is presented in Section 2. Section 3 describes charging and discharging strategies. Experiments results and discussions are presented in Section 4. Section 5 gives conclusions and discusses a future work.

2. Related work

Over the past 20 years, researchers have been searching for new and alternative energy systems. There have been various attempts to develop concepts for distributed energy generation from renewable sources, as well as new designs for energy distribution and storage. Some researchers aim to make use of existing infrastructure and make the transition to a new system as seamless as possible, while others believe that starting from scratch with the option of integrating into the existing electrical grid is the best approach.

Rikiya Abe et al. in 2011 for the first time have presented an idea of a digital grid (IEEE Transactions on Smart Grid). They have been presented a new concept of a grid as a splitting electrical grid into cells and connect them with an electrical device to control the energy share between the cells. They have presented the design of the proposed system with very little details, lacking operation examples or simulations. At the same time the research also lacks analysis and integration overview from the penetration of RES into the digital grid [6].

The idea of grid digitalization was growing very fast in some smaller projects, such as an Open Energy System research in Okinawa Island in Japan [7]. There is a direct current (DC) based Open Energy System (DCOES) joint research project. This project was researching on a DC-based bottom-up system that generates, stores, and shares electrical energy. Annette Werth et al., in "Evaluation of centralized and distributed microgrid topologies and comparison to Open Energy Systems" (IEEE International Conference on Environment and Electrical Engineering 2015) study was examining microgrid topologies that combine solar panels and batteries for a community of 20 residential houses [8]. They consider a system with centralized PV and batteries that distributes energy to the 20 homes, they also consider 20 standalone homes with roof-top PV and batteries.

The virtual synchronous generator has gained significant interest as it operates similarly to a synchronous generator, making it a viable option for connecting distributed generation to the main power grid. However, the power and frequency output of a virtual synchronous generator can be unstable during significant power fluctuations in the distributed generation system. Fei Wang et al. studied how changes in parameters affect the active power and frequency of a virtual synchronous generator. They analyzed the impact of power fluctuations and developed a small-signal model to understand the dynamic behavior. Based on their research, they proposed a new adaptive control strategy and confirmed its effectiveness through experiments [9].

Hui Guo et al. published their research (IEEE Transactions on Industrial Informatics 2019) on the basis of bidding information. The real-time transaction was implemented to track the origin and destination of power transmission, as well as the amount and timing of power flow. To minimize losses from conversion and transmission, a minimum loss routing method was chosen for the transaction of power. The proposed optimization algorithm for selecting the minimum loss routing and managing congestion was confirmed through simulation results. [10].

Lijun Zhang et al. are researching on a novel matrix converter - based topology to be applied in smart transformers based on the concept of multiple modularity. The conventional smart transformer topology, which uses H-bridge modules and DC electrolytic capacitors, was replaced with a new design that utilizes two matrix modules for greater flexibility in AC-AC structures. This new design was thoroughly analyzed, including a detailed examination of the impact of switching sequences on capacitor voltages. To validate the proposed topology and its analysis, simulations and hardware-in-loop experiments were conducted. [11].

K. Chaudhari et al. proposed a hybrid optimization algorithm for energy storage management, which shifts its mode of operation between the deterministic and rule-based approaches depending on the electricity price band allocation. The cost degradation model for the energy storage system (ESS) and the levelized cost of photovoltaic (PV) power was applied to electric vehicle (EV) charging stations. The algorithm was divided into three parts: classifying real-time electricity prices into different categories, determining the real-time PV power from solar radiation data, and optimizing the operating cost of the EV charging station that combines PV and ESS to minimize expenses [12].

Another battery energy storage system based on direct method to control the power converter for fast compensation of grid voltage instability without energy management system has been proposed by D. -J. Kim et al. A new approach for improving the power quality at an electric vehicle charging station (EVCS) has been developed. This method uses a model predictive voltage control scheme that is based on a disturbance observer, and it operates without the need for communication infrastructure. The proposed controller takes into account parameter uncertainties and uses a systematic design procedure that includes stability analysis. The performance of the controller was verified through tests using a simulation testbed that was designed to closely resemble an actual EVCS. [13].

Daniel Kucevic's et al suggest a system for managing multiple battery energy storage systems located at electric vehicle charging stations within a distribution grid. The method involves linear optimization and time series modeling, with the goal of reducing peak power levels. A simulation tool was created to combine a power flow model with a battery energy storage system model to better understand the impact of storage systems on the distribution grid. [14].

Another research was done on occupant behavior data collection. This paper introduces a dataset of electricity usage in residential homes in Uruguay that was collected by the Uruguayan electricity company (UTE) and studied by Universidad de la República. The purpose of the dataset is to analyze consumer behavior and uncover patterns of energy consumption that can be used to improve electricity services. The dataset is publicly accessible and stored in a public repository. It is confirmed by three subsets that cover total household consumption, electric water heater consumption, and energy consumption by appliance, with sample intervals from 1 to 15 minutes. The total household consumption subset includes the total aggregated consumption of 110,953 households distributed in the 19 departments of Uruguay. On average, each household was monitored for 539.2 days and each day counts with 95.2 records [15].

Salvatore Carlucci and etl in their work on modeling occupant behavior in buildings studied reviews approaches, methods and key findings related to occupants' presence and actions (OPA) modeling in buildings. A comprehensive collection of research papers on the subject has been assembled and analyzed using bibliometric techniques. The initial review uncovered over 750 studies, with 278 selected for further analysis. These publications give a comprehensive overview of the progress and evolution of OPA modeling methods. The methods in the chosen literature have been divided into three categories: rule-based models, stochastic OPA modeling, and data-driven methods for modeling functions related to occupancy and the actions of occupants. [16].

Moreover, currently renewable energy generators have installation limitations in the modern power grid due to both technical and policy reasons, which further complicate the penetration of RES to energy mix models. Authors in [17] discuss the challenges of renewable energy penetration on power system flexibility.

3. Adaptive charging and discharging approach

Electrical energy storage in batteries is becoming a crucial thing in our life. We use batteries in mobile phones, watches, laptops, and headphones. Batteries have been used in cars for decades, but with the popularization of electric vehicles (EV) it has become especially important. Now we see more and more in-house appliances which benefit from utilizing batteries, such as electric toothbrushes, audio speakers, hair trimmer, cordless vacuum cleaner, and so on.

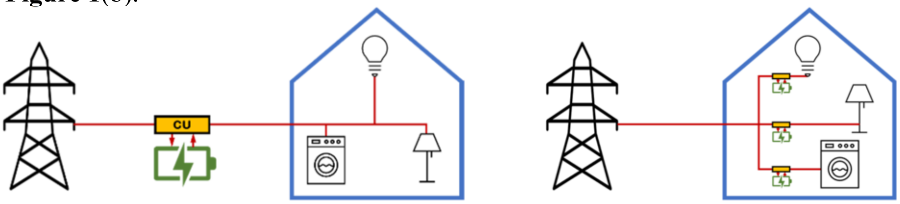
There are a number of benefits that can be achieved for an appliance when there is a battery, such as:

- less dependent on energy availability, for example when a solar panel was used to charge a device, the device can be further used when the sun no longer available;
- in case of short power outage times a device with a battery is still powered and ready for use;
- high power consumption of a device can be replaced with a lower charging power spread over longer time, so the power line to utility can be lower;
- the device becomes free from socket and wires, so it can be carried along with the user inside and outside of the house.

Even though batteries possess several advantages when utilized in appliances, it is important to acknowledge that there are also disadvantages and limitations associated with the usage of batteries as well:

- battery capacity is limited, so in some cases there may be insufficient amount of energy to complete a desired activity, other kinds of devices might be using too much energy that those can hardly be powered with a battery of reasonable size;
- batteries degrade over time, their capacity goes down, and may even have to be replaced in order to keep using the device;
- device with a battery is typically more complex and more expensive compared to similar analogues without a battery;
- devices with batteries usually are not able to share energy between each other, such that a mobile phone cannot be recharged from a cordless dust sucker;
- batteries have to be recharged from time to time to keep working, so the freedom from wires and sockets is limited.

In this work we consider a standalone energy storage device consisting of a battery and a Control Unit (CU). It can be plugged between the utility main line and any device. The layout for a customer can be set up as a single shared battery for the entire household as shown on **Figure 1**(a) or an individual battery per every appliance device as shown on **Figure 1**(b).



a) b)

Figure 1. Setup layout options: a) one shared battery per customer, and b) individual battery per device.

There are advantages and disadvantages to both setup layouts. On one hand, installing a single large battery for a house looks reasonable and simpler. But on the other side, every device has its own usage pattern, power, and priority. So, it would make more sense to setup individual battery per appliance with proper characteristics matching the device electricity usage pattern.

Going further, combination of both options gives one more setup layout, where individual batteries work for targeted devices and a shared battery for the entire consumption of the customer. Also, when there is a shared energy storage system for a private house, there is also typically a private micro-generator installed in the system, such as a solar PV panel. **Figure 2** shows a more realistic setup.

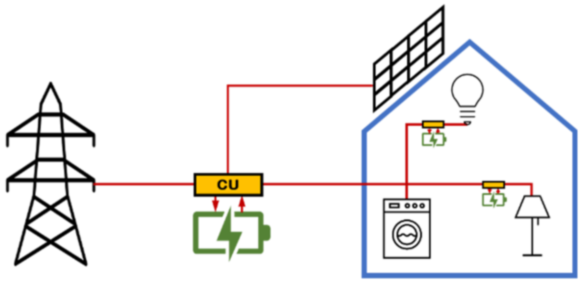


Figure 2. Mixed setup layout of batteries and use of private energy generation source, such as PV.

In a simple case we have a battery which is being used until fully discharges, and then the remaining part of the demand has to be covered from the utility line. This scenario is shown in **Figure 3.** Scenario, where battery is fully used until it gets totally discharged and the remaining time is covered by utility power line. This approach is good enough when battery capacity is large enough and periods of electricity demand by the consumer devices are short, so that battery capacity is larger than amount of electrical energy consumed during one session of device usage.

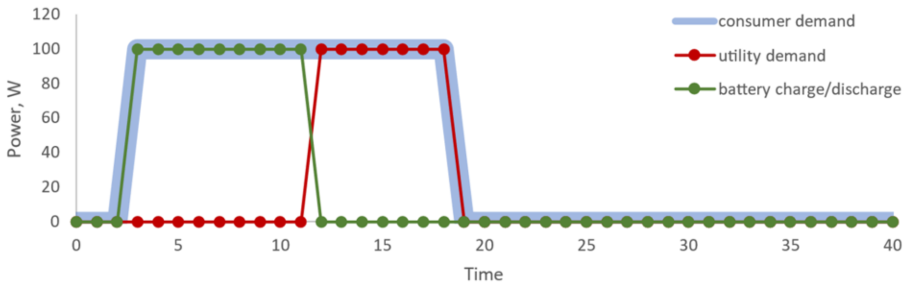


Figure 3. Scenario, where battery is fully used until it gets totally discharged and the remaining time is covered by utility power line.

In the scenario described in the **Figure 3**, the consumer device was fully supplied with the energy it needed. However, after the described case the battery is totally discharged, and it would not be possible to use it for the next session of consumer device usage. Battery charging has to happen along the way so that the overall process tends to optimize the battery usage.

Batteries, charging and discharging can happen in various ways. In this paper we do not touch the details of the technical differences of various types of batteries, as well as we do not target the differences in technical requirements of charging specific kinds of batteries.

In this paper a battery is conceptually viewed as an device for the storage of electrical energy that operates through the process of charging and discharging. The amount of stored capacity of a battery is increased through the charging process, which allows a predetermined amount of energy to be accumulated. This stored energy can be recovered upon demand through the discharge process. The fundamental properties of a battery are defined by a set of characteristic parameters:

- capacity,
- maximum charge power,
- maximum discharge power,
- storage efficiency.

The approach of determining when the battery has to take energy for charging, when the energy has to be given back, and by what power, depending on consumer demand, battery internal state, as well as other possible factors is called charging and discharging strategy.

We assume that energy demand can be covered not only from one of two sources, but also as an arbitrary mix of two of these sources. For example, 65% of energy is taken from a battery and the remaining 35% from utility line at any point of time. This can be achieved through various methods, such as by means of transformers, AC/DC converters, smart energy routers [18, 19], pulse-width modulation (PWM), etc. The efficiency and choice of the mix method is outside of the scope of this paper.

One of the options for taking the internal state of the battery into account is to discharge battery proportionally to the state of charge. In that case, when the battery is charged to 100% the consumption demand is fully covered by the battery. When at time *t* battery has 85% of its charge then only 85% of load power at time *t* will be covered by the battery and the other 15% should be taken from the utility. That way, battery use decreases exponentially over time which makes battery being used longer although covering only part of the demand power. At the same time, utility demand power is lower and increases gradually rather than as a step when the device is turned on. This case is displayed in **Figure 4**. This approach can be called discharge strategy *S* which is based on battery state of charge (SoC), and no charging was involved.

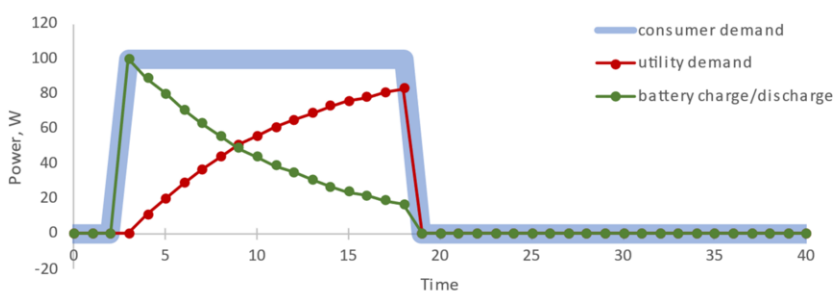


Figure 4. Scenario with proportional discharge strategy.

Calculation formulas for battery charge power P_{BC} and battery discharge power P_{BD} are as shown in (1.1) and (1.2). Where P_D is a consumer demand power, P_{CMAX} is maximum charge power, P_{DMAX} is maximum discharge power, F_C and F_D are charge and discharge strategy functions based on battery internal state.

$$P_{BC} = F_C(SoC) \times P_{CMAX} \tag{1.1}$$

$$P_{BD} = min(P_D \times F_D(SoC), P_{DMAX}) \tag{1.2}$$

That way we get battery power P_B as a difference between the discharge and charge power as shown in (2). When P_B is greater than zero, battery is discharging, when it is below zero it is charging.

$$P_B = P_{BD} - P_{BC} \tag{2}$$

Available capacity C_{AV} would be defined as differential equation as shown in (3.1) and which can be expanded in (3.2).

$$\frac{dC_{AV}}{dt} = -P_B = P_{BC} - P_{BD} \tag{3.1}$$

$$\frac{dC_{AV}}{dt} = F_C(SoC) \times P_{CMAX} - min(P_D \times F_D(SoC), P_{DMAX}) \tag{3.2}$$

Utility demand power P_U in turn is defined as a remaining power that is required to cover the consumer demand and battery charge, taking into account charge efficiency E_C, as shown in equation (4).

$$P_U = P_D - \frac{P_B}{E_C} \tag{4}$$

Charging and discharging strategies functions are defined as multiplier in range between 0 and 1. In the simplest case, these functions may always return 1 which would mean that the battery charges at the maximum possible power, as well as discharges at the maximum power according to demanded load.

Table 1. Charging and discharging strategies

Strategy	Function	Charge	Discharge
S_1	$f(x) = x$	CS_1 - Proportional	DS_1 - Proportional
S_2	$f(x) = x^k$	CS_2 - Optimistic	DS_2 - Wasteful
S_3	$f(x) = \sqrt[k]{x}$	CS_3 - Greedy	DS_3 - Economical
S_4	$f(x) = 1/\left(1 + e^{-k(x-0.5)}\right)$	CS_4 - Balanced	DS_4 - Balanced
S_5	$f(x) = 1$	CS_5 - Full charge	DS_5 - No use
S_6	$f(x) = 0$	CS_6 - No charge	DS_6 - Full use

In this paper we have taken 6 strategies for both charging and discharging to compare, so the overall battery available capacity over time depends on the battery state of charge (SoC), demand power, maximum charge power and maximum discharge power. The strategies are described in **Table 1**. The functions are represented in **Figure 5**.

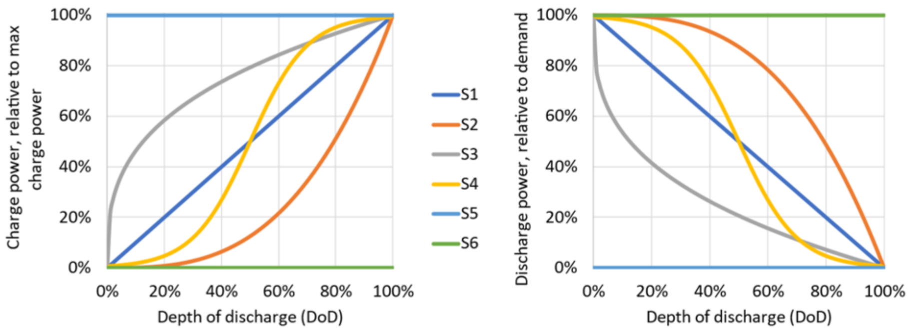


Figure 5. Charge and discharge strategies based on battery state of charge.

4. Experiments and Discussions

Residentials depend on electricity constantly, because a lot of appliances are working simultaneously, such as refrigerator, electrical heating, air conditioning, microwave, and so on. When an electrical issue arises, for example a power failure caused by a storm or there is a tripped breaker or any other problem with electricity in the circuit, the understanding of how an electrical system operates can be valuable in resolving the problem and restoring the power.

Experiments on Strategies. Comparison of the strategies is performed on reference demand signal which is 100 W consumption over 16 seconds. Battery capacity is set to be 0.25 Wh. The comparison results of strategies experiments $CS_1 - CS_6$ and $DS_1 - DS_6$ are presented in **Figure 6**.

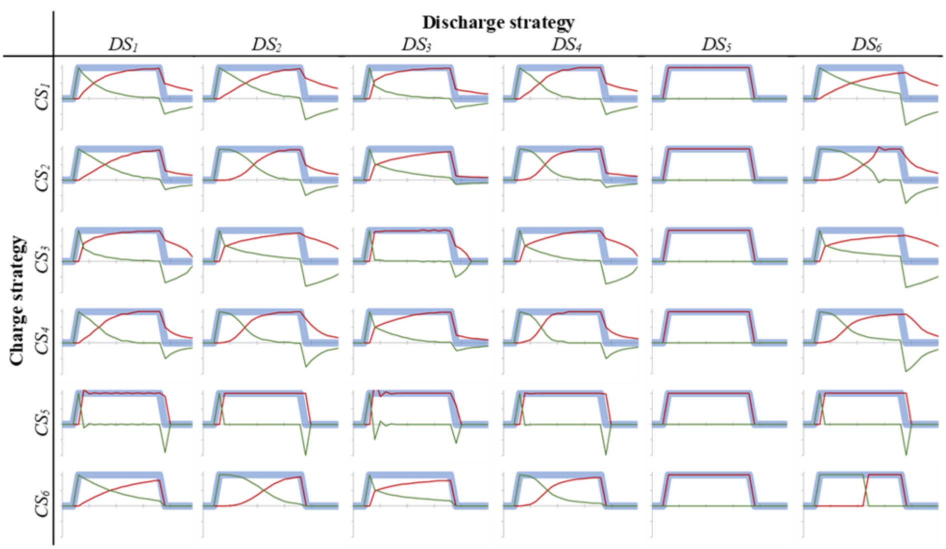


Figure 6. Charge and discharge strategies comparison.

In these experiments we can see that all cases with strategy DS_5 end up with the battery not involved in the process. A very similar situation can be seen with the charging strategy CS_5. At the beginning of the demand battery tries to cover the demand, but then battery usage is quickly reduced by the aggressive charge strategy, and even in some cases fading oscillations appear in front. Strategy CS_6DS_6 is identical to full use of battery until it is completely discharged and then the energy source is switched to utility line. All other strategies use battery and recharge it in different ways.

Strategies where discharging is DS_3 and where charging is CS_3 are mostly preserving the energy in the battery and it can be seen that utility demand quickly raises to power of the customer demand. In many cases we see that utility demand starts to raise immediately when the consumer demand increases. Although, there are several strategies, such as CS_2DS_2, CS_4DS_2, CS_2DS_4, CS_2DS_6, where utility demand stays close to zero for some time, so the device tries to cover the customer demand only by utilizing the battery.

Experiments on Capacity show that the system behavior was evaluated depending on various battery capacity sizes. In **Figure 7** are shown the results diagrams for the strategies CS_1DS_6 and CS_4DS_2 over battery capacities 0.25 Wh, 0.5 Wh, 1 Wh, 2 Wh, and 4 Wh. We can see that, when the capacity of the battery is getting bigger the strategies in both cases tend to use only battery power.

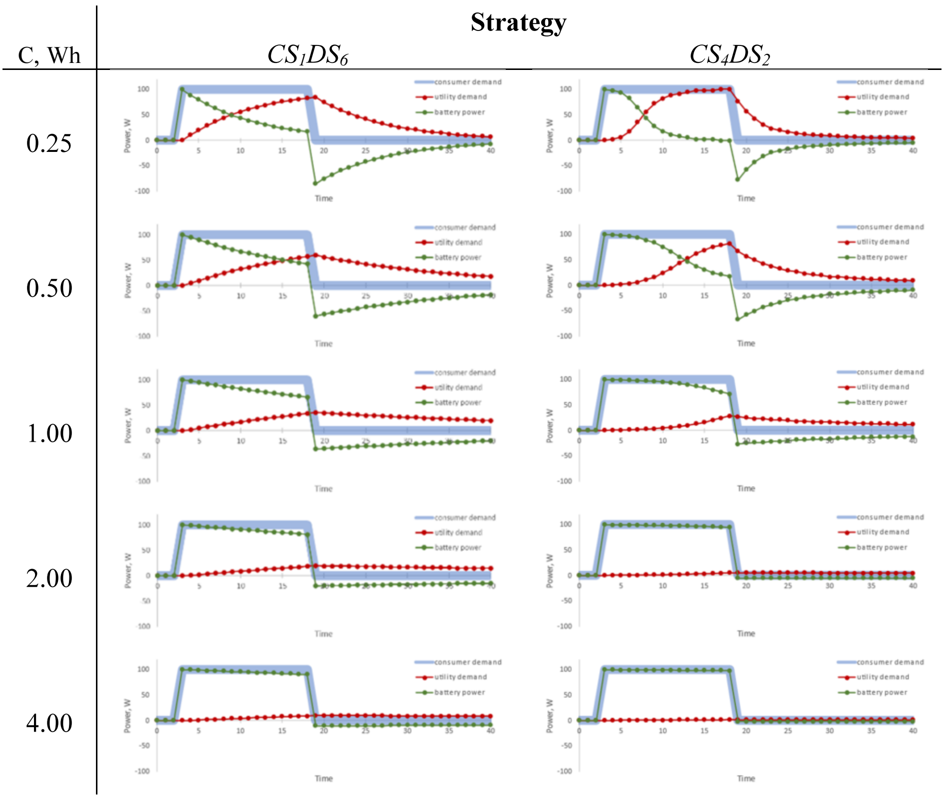


Figure 7. Comparison of strategies over battery capacity.

The main difference of the strategies plays a role when the consumer demand drains the battery significantly. Given the 100 W consumption over 16 seconds makes the total energy of the consumption demand data equal to 0.44 Wh. So, for the case of strategy CS_4DS_2 when the battery capacity is twice as much as the consumed energy of the customer, the power is almost fully covered by the battery.

Experiments on Power Limits. In these experiments, the system behavior was evaluated depending on reduced charge power and reduced discharge power options. In **Figure 8** the diagrams for the strategy CS_4DS_2 are shown. We can see that when only charge power is limited, it affects the result insignificantly. But when both charge power and discharge power are limited, the overall result becomes different to the initial setup.

The case when $P_{CMAX} = 20$ and $P_{DMAX} = 20$ shows that when limits are below the demand power and battery capacity is enough then the system behaves as a mechanism for utility line power reduction for a given margin.

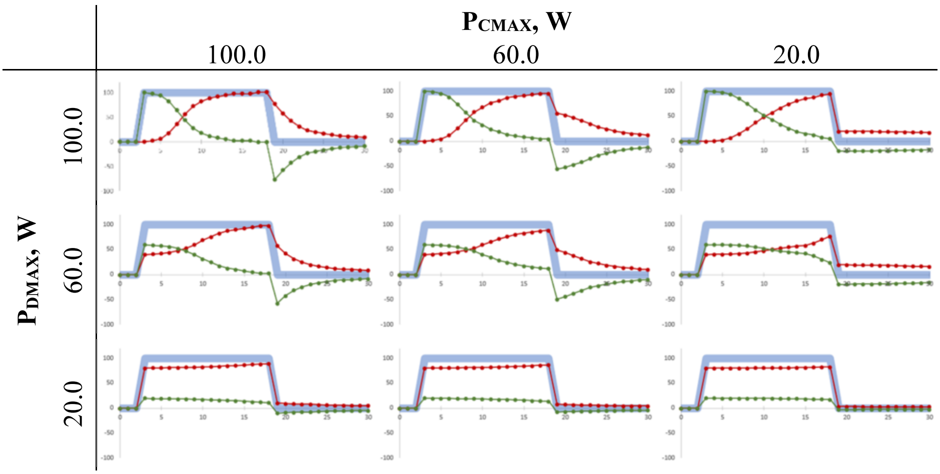


Figure 8. Comparison of strategy behaviors with limitations of maximum charge and discharge power.

Experiments on Demand Shape. During experiments on demand shape the system behavior was estimated on various kinds of consumer demand signal types. **Figure 9** shows the diagrams for the strategies CS_1DS_6 and CS_4DS_2 with battery capacity equal to 0.25 Wh, and charge/discharge limits of 100 W, which is above the demand power. Types of input signals included one-time session of demand, periodic load, increasing load as a step, and decreasing load as a step. In the considered cases strategy CS_1DS_6 provides a smoother utility demand power, because it utilizes battery more intensively.

The scenario of decreasing demand is quite a typical case when a device needs more power right after startup but then the demand decreases. Both strategies which are shown in the comparison results covered the front peak very well.

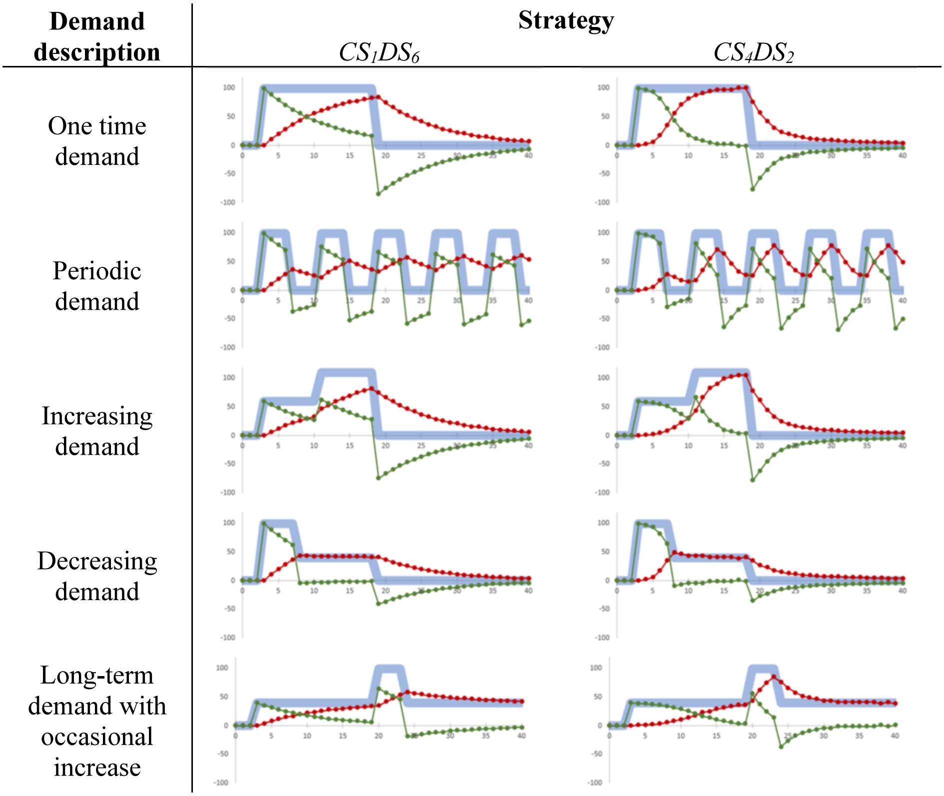


Figure 9. Comparison of strategy behaviors on various types of demand signal.

Experiments on Uruguay Dataset. In these experiments we have used data, which was collected during the research work on information on the behavior of electricity users. This research presented a dataset of electricity consumption in residential homes in Uruguay, collected by the Uruguayan Electricity Company (UTE) and analyzed by Universidad de la República [15, 20]. The goal of the dataset is to study occupants' behavior and discover patterns of energy consumption that can improve the electricity service. The dataset is open to the public and consists of three parts, which focus on overall household consumption, consumption by electric water heater, and energy usage by appliance, with time intervals ranging from 1 to 15 minutes.

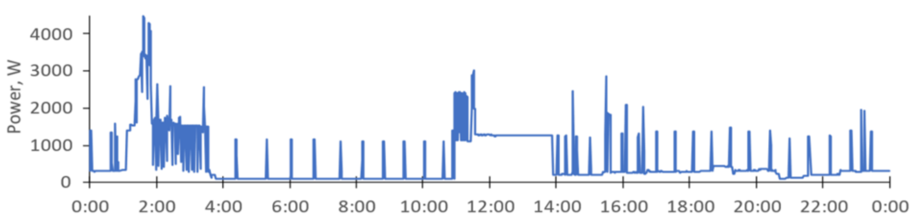


Figure 10. Load dataset example of one household (customer id 170004, date 2019-09-11).

The utility company is responsible for ensuring that electricity is supplied to residential properties. This includes maintaining the power lines up to the attachment point, which is referred to as the load side. From this point, the responsibility for ensuring that the electrical system functions properly falls on the homeowner. This includes addressing issues such as circuit overload, which can cause power outages. It is important for occupants to understand their responsibilities when it comes to the electrical system in their home in order to ensure that it operates safely and effectively.

A circuit overload means that there are too many high-powered appliances operating on the same electric circuit, for example hair dryer, air conditioner, washing or tumble-dryer machines, electric kettle, etc. An overloaded circuit means that occupants are using more electricity than the circuit is made for. In such a case the electrical system in a residence will experience a shutdown due to a circuit breaker in the service panel being triggered. Circuit breakers are a reliable solution for preventing electrical fires caused by overloads, but the safest approach is to manage electricity usage to avoid overloads in the first place. By taking proactive steps to control electricity usage and avoid overloading the system, homeowners can help ensure the safety and stability of their electrical system.

In this paper we have used the Disaggregated Energy Consumption by appliance dataset, which consists of two relevant data: the total aggregated consumption records of nine households in Montevideo, and the disaggregate consumption of a set of appliances in each household (e.g., lamps, fridges, air conditioner, etc.). The sampling interval is one minute, and the date range of consumption records is from 27th August 2019 to 16th September 2019. Appliances vary by customer and typically include dehumidifier, tumble dryer, microwave, electric oven, electric air heater, washing machine, fridge, electric water heater, and air conditioner.

The breakdown of the load demand data for customer id 170004 for entire day of 2019-09-11 is shown in **Figure 11**.

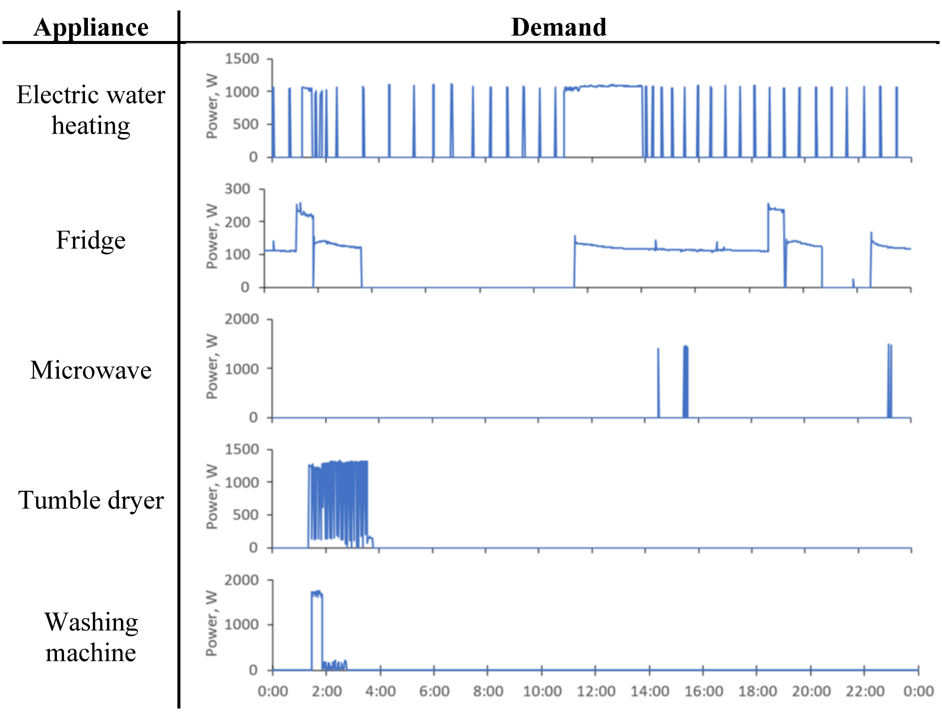


Figure 11. Breakdown of the load demand data by appliance.

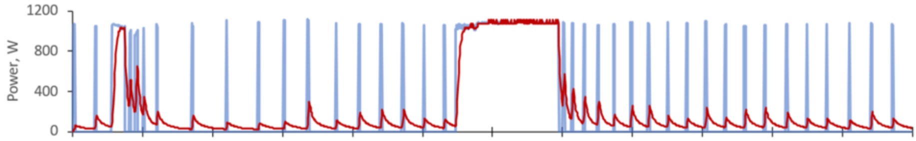


Figure 12. Electric water heating appliance demand with battery 250 Wh.

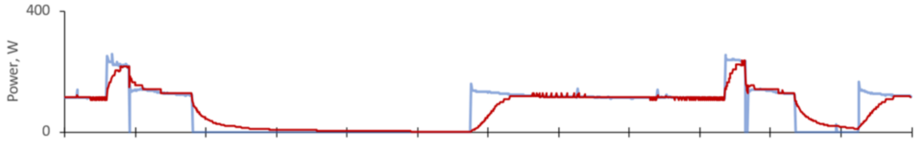


Figure 13. Fridge appliance demand with 300 Wh battery.

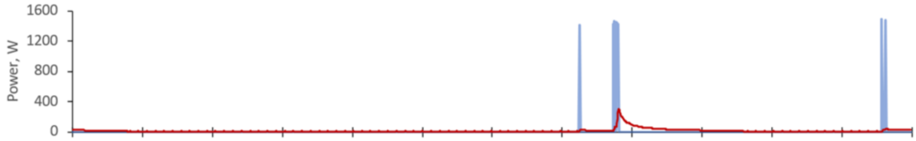


Figure 14. Microwave appliance demand with 500 Wh battery.

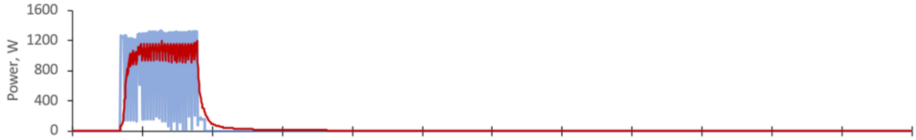


Figure 15. Tumble dryer appliance demand with 300 Wh battery.

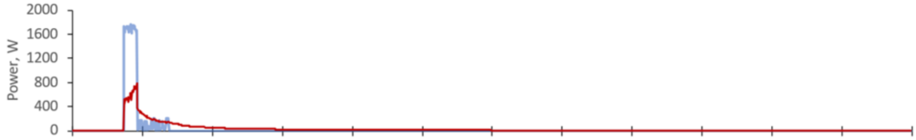


Figure 16. Washing machine appliance demand with 1000 Wh battery.

Every appliance had its own individual battery. Its capacity was chosen individually based on the appliance demand. Capacity of batteries in the presented experiments make up a total of 2350 Wh. The same amount can be used as a single shared battery instead or can be shared between appliances in a different split in mixed layout. The details of the considered cases are presented in **Table 2**.

Table 2. Battery capacities split by appliances and by experiment cases.

Battery	Appliance	Capacity, Wh		
		Case 1	Case 2	Case 3
Individual	Electric water heating	0	250	250
Individual	Fridge	0	300	0
Individual	Microwave	0	500	500
Individual	Tumble dryer	0	300	0
Individual	Washing machine	0	1000	600
Shared	Entire household	2350	0	1000

The comparison of results is shown in **Figure 17**. We can see that all cases give relatively similar output. Although, many short-term load periods are smoothed out, the Case 2 where only individual batteries were involved, we can see that water heater battery capacity was not enough to avoid medium peaks. Those medium peaks are especially visible in the period between 14:00 and 16:00. Longer-term periods remain almost the same as in the original customer demand.

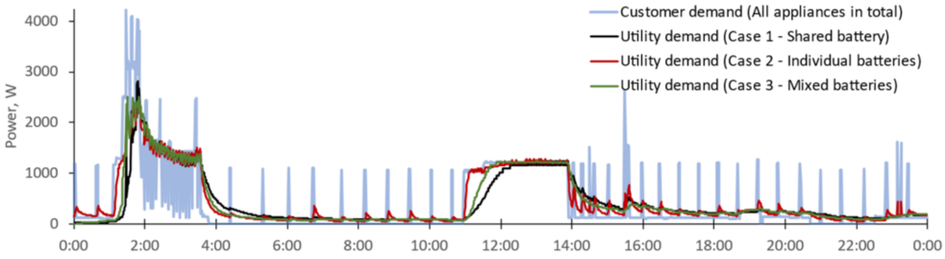


Figure 17. Comparison of results for shared battery, individual batteries, and mixed batteries layouts.

Various kinds of appliances have significantly different level of load power, however the importance and priorities of such appliances for the customer is very different. Therefore, mixed layout of batteries as in Case 3 becomes a good choice, and the battery sizes is the subject for configuration per customers individually based on appliances and their usage patterns.

In this set of experiments the overall peak was significantly lower for all cases with batteries compared to consumer demand. The comparison is given in **Table 3**. We can see that with the use of batteries, the peak power has decreased to approximately 60%. This is a significant value which contributes to reducing the utility power line and generation peaks which are in general more expensive.

Table 3. Peak power comparison for experiment cases 1-3.

Scenario	Peak power, W	Relative
Customer demand (All appliances in total)	4213.00	100.0%
Utility demand (Case 1 - Shared battery)	2817.06	66.9%
Utility demand (Case 2 - Individual batteries)	2484.16	59.0%
Utility demand (Case 3 - Mixed batteries)	2518.11	59.8%

5. Conclusions and future work

Energy generation and consumption in the world have significant challenges in terms of energy security and environmental degradation. Renewable energy sources help to address these challenges significantly and therefore have become very widespread in recent years. However, to fully switch to renewables the generated energy has to be stored and used when renewable resources are not available. In such a case it is hard to underestimate the importance of energy storage systems for the modern world and Smart Grid systems.

This paper introduces an adaptive charging and discharging approach with various strategies based on energy availability and energy demand. We propose a model which controls battery use based on consumption demand and selected charging/discharging strategy represented in the form of a function of battery internal state. In the model we take into account battery total capacity, available amount of energy in the battery in a given time, charging strategy, discharging strategy, energy storage efficiency factor, maximum charging and discharging power. Six strategies have been defined which can be applied for both charging and discharging.

The experiments present the comparison of adaptive energy storage system behavior depending on various setups of strategies, battery capacity, demand load signal, and power limits. Disaggregated energy consumption by appliance dataset of nine households in Montevideo from Uruguay was used in this paper. Three batteries setup layouts for a household were compared, which include the layout of individual batteries per appliance, single shared battery for entire household, and a mixed approach.

In the future work we plan to extend the strategies to take into account utility cost of electricity which varies during the day. We plan to include private microgeneration options as well as to explore in more details the optimal battery capacity split between appliances.

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