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Economic Feasibility of Micro-Grid Energy Storage and the Impact of Emerging Technologies on Its Viability

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Abstract

Currently, energy storage devices show great promise when used in micro-grid applications, and further advancements in this technology will lead to economically-viable and environmentally-friendly solutions in regards to residential energy consumption. Creating a 21st-century energy infrastructure will be fundamental to society in the coming decades and ensuring cost-effective means of doing so will lessen the burden on the average consumer. While current research has focused primarily on fundamental battery research, the economic viability for the average American consumer has been neglected in many cases. In this work, current and future methods of home energy storage are analyzed via a thorough literature review and the most promising current and near-future methods are explored. These methods include current Lithium-Ion Battery (LIB) technology, reused LIB from Electric Vehicles (EVs), Lithium Nickel manganese cobalt oxides (NMC) cathode composition and the utilization of silicon as an anode material. After the potential of these technologies is explored, an analysis of their economic viability for the average consumer is presented. The literature review demonstrates that the current state of LIB is very close to economically feasible; reused LIBs are less viable than new LIBs, and future LIB compositions show great promise in viability. This shows that within the next decade, micro-grids will be a reasonable alternative to utility energy harnessing techniques, and a major step towards green energy consumption will be realized. Hybrid energy storage systems, on the other hand, are shown to be economically infeasible, in the near future, due to their high cost per kWh. However, when analyzing the energy storage capabilities of these systems, it is shown that they may be vital in updated energy infrastructure and provide a cost saving.

Keywords

Lithium-Ion Battery, Micro-Grid, Hybrid Energy Storage, Cost Analysis

1. Introduction

The switch to renewable energy sources in the 21st century has been a slow one, mainly due to the high cost of upgrading the current first-world energy infrastructure. In recent years, there has been an inconsistent degree of international commitment to enhancing this infrastructure, due to the high cost of the initial investment. Ultimately, this high up-front cost has mainly been passed to consumers if they are interested in a modern energy solution. Due to this overall strategy, many worldwide locations have been left with unreliable, non-environmentally friendly, and outdated energy infrastructures. There is a need to understand at what point these technologies will attain the level of economic feasibility for the average consumer.

In this work, the economic feasibility of microgrids for the average consumer is explored, with an emphasis on energy storage cost, as this is where much of the initial investment is placed. The need for more robust residential energy options will continue to increase well into the 21st century as the demand continues to increase due to more nations reaching the standards of the developed world. An example of this is outlined specifically by China in the 2000s. Residential energy consumption more than doubled in the time between 2002 and 2010 in China as the result of a growing middle class, as outlined in [1]. This social phenomenon is expected to continue worldwide as more East Asian, Middle East, and African countries develop economically.

The importance of energy storage solutions in conjunction with reusable energy cannot be overstated, primarily, due to the large amounts of energy that are lost when effective energy storage is not utilized. This is mainly due to energy generation and energy utilization not being synchronous. A key factor for this is the structure of modern life, which places most people out of the home during hours in which energy generation of photovoltaic cells is the highest (middle of the day). This creates a situation in which high amounts of energy are created but are not utilized if energy storage is not implemented.

When energy storage devices are considered within the context of microgrids, common solutions tend to favor batteries. Even though this, as of now, is the most economical solution, other techniques can be utilized. Specifically in this work, the concepts of hybrid energy storage systems will be explored. These systems utilize batteries, which act as a low-power, high-energy density solution in conjunction with supercapacitors or flywheels, which add a high-power, low-energy density component to micro-grid energy storage. The energy storage environment is a dynamic one, with new battery material, such as, graphene being introduced alongside other innovative solutions which include reused and recycled batteries. Understanding how these emerging technologies can be useful in micro-grids is fundamental to solving the energy problem and helps in discovering solutions for affordable energy generation.

After reviewing various potential solutions for micro-grid energy storage, a cost analysis of the proposed solutions will be performed in detail. What is un-

covered by looking deeper into the economic feasibility of these systems is that the hybrid energy storage technologies have not yet reached the point of feasibility but their high-power output capabilities show great promise. Future battery technologies, such as NMC, will be ideal for residential energy storage. Although, until this time comes, it is suggested that infrastructure investments by governments may be utilized to push the energy grid forward.

2. Literature Review

2.1. Micro-Grids

Micro-grids are defined as "electrical infrastructures that serve diverse users from a single building up to an island and can be interconnected and interact with the main utility grid or operate independently based on distributed energy generation" [2]. There are six main components to a micro-grid starting with the most fundamental, the energy generation source, which can be renewable or non-renewable [2]. Sources of renewable energy include photovoltaic cells or wind turbines. An example of non-renewable energy sources would be a diesel power generator. Other components include power conditioning systems, energy storage, management and control systems, and distribution network [2]. In this research review, the energy storage systems will be studied in more depth and categorized into two separate classifications, each of which has its own advantages. These two energy storage solutions are battery storage, which only utilizes batteries, and hybrid energy storage, which utilizes batteries in tandem with a high-powered energy storage device, such as, a flywheel or supercapacitor.

One of the benefits of the above listed energy storage solutions is a diversified energy infrastructure that is less prone to outages. The current energy infrastructure could be viewed as weak due to its lack of diversity and is susceptible to grid attacks, which could cause issues for large regions. The alternative is a diversified network in which attacks will affect a smaller number of people. Also, from an economic standpoint, micro-grids are beginning to gain some traction. This is mainly due to an increase in the cost of utility-style energy solutions in comparison with micro-grids. This reduction in the cost for micro-grid energy solutions can be realized when comparing the levelized cost of energy (LCOE) for micro-grids in 2005 and in 2015. In 2005, the LCOE of micro-grid systems varied between 1.05 and 1.57 US$/kWh, and in 2015 that price had decreased to 0.61 - 0.92 US$/kWh [2]. Within the list of systems that are arranged to create micro-grid systems, the energy storage component is the one that shows the most potential for decreasing the overall cost of micro-grid systems, and therefore will be highlighted further.

2.2. Battery Energy Storage

As previously mentioned, battery energy storage is fundamental to microgrid success in the future. Battery energy storage allows for the maximum utilization of energy created by microgrids. Some of the main drawbacks associated with

battery energy storage are its low power ability and its relatively low cycle life when compared to some higher power energy storage devices. These specific drawbacks have been explored in fundamental battery research, such as, graphene-based anodes and lithium air batteries. The graphene battery, in particular, solves some of the standard issues associated with batteries by providing an atypically high current density of 770 mAh/g and maintains 98% of initial capacity after 110 cycles [3]. However, currently the cost/kWh of commercially available graphene batteries is approximately $2247. These batteries are generally used in very specified, lightweight applications. The reason for the unusually high cost of graphene battery when compared to the standard Lithium-Ion battery, which currently is at about $125/kWh, is the cost of graphene manufacturing, which is still relatively immature in its development. Another emerging battery technology is Lithium-Air cell, which can provide 10 times the energy density of the standard Lithium-Ion battery [4]. The main issue currently associated with Lithium-Air cell is the inability to scale production. Some of the main hurdles associated with this technologies' feasibility are "voltage stability, charge over potential, electrolyte stability, and many other physical-chemical factors that should ideally include full cell development that operates in ambient air" [4].

Two types of battery chemistry that show promise in the near future for both micro grids and EVs are NMC for the cathode material and graphite for the anode material, or utilizing this cathode chemistry along with the use of silicon for the anode. The benefit of the NMC cathode, when compared to a more traditional Lithium-Ion battery cathode, is the decreased use of cobalt and an increased use of nickel, whose economic viability will be discussed later [5]. Some of the issues associated with the emerging cathode technology include its low power and energy density degradation. However, more recent compositions of this type show increased performances in this area when compared to commercially available products. An example is the comparison of the emerging composition with the legacy—150 cycles at 25 degrees Celsius with voltage ranges from 2.8 and 4.45 volts at 1 degree Celsius. The commercially available product had a Coulombic efficiency of 89.1 and 88.9 percent, compared to the 99 percent that was shown from the advanced composition [5]. Also, the advanced composition was shown to have a superior cycling retention at 150 cycles of 81.6% compared to the 59.4 percent of the legacy [5]. The other advancement that can be considered in these emerging battery compositions is in the utilization of a silicon anode as opposed to the more traditional graphite anode. The benefit of utilizing silicon as opposed to graphite, as the anode material, is in the form of increased theoretic specific capacity from 440.5 mAh/g to 4200 mAH/g [6]. However, these advantages come with some disadvantages, such as large volume changes, low conductivity, and faster energy density degradation [6].

Another innovative option for energy storage in relation to micro-grids is in the form of reusable batteries from electric vehicles (EVs). The reason this option appears to be very promising is associated with one of the major drawbacks of the current state of Lithium-Ion Batteries.: their degraded energy densities as

a function of cycles. This means that as the batteries are continuously cycled, as they often are in both EV and micro-grid scenarios, the amount of energy that the batteries can store also decreases. As a result, when the batteries of the EVs are degraded to the point of about 80 percent of the initial capacity, their ability to be effective energy storage devices (specifically for EVs) is diminished, but because of the lessened focus on energy density of the energy storage systems for micro grids, they can find a second life. Estimated costs for these reused battery systems are anywhere between $38 - $132/kWh, which would be a great reduction from the cost of new battery packs [7]. The remaining issue is that the cost needs to be recurred over a shorter period of time due to the fact that they are degraded from the onset.

Lastly, recycled batteries are also crucial to the long-term energy storage plan for microgrid energy storage. The reasons are many, but specifically, the demand Lithium-Ion batteries has for the world's cobalt and lithium supply is unsustainable, and 50 percent of the total cost of the batteries is directly associated with material cost [8]. Cobalt itself is one of the most financially unstable materials utilized within Lithium-Ion Batteries, and its cost fluctuations can be seen in Figure 1 [8].

Looking at Figure 1, it is observed that over the course of about a year, cobalt prices varied significantly, while nickel prices had stayed relatively stagnate [8]. The goal for the new compositions of cathodes is to decrease the percentage of cobalt utilized and replace that with nickel [9]. Another challenge, when it comes to supply chain management, is related to the acquisition of raw lithium for the cathode material, which can be visualized in Figure 2 [9]. The supply risk caused by lithium is a function of the growing energy storage market, which can be understood when analyzing how China's battery material production increased from 4 kt Li, 25.5 kt Co, 7.7 kt Ni, and 54.7 kt graphite in 2013 to 9.5 kt Li, 38.4 kt Co, 16.7 kt Nic, and 122.6 kt graphite in 2016 [9].
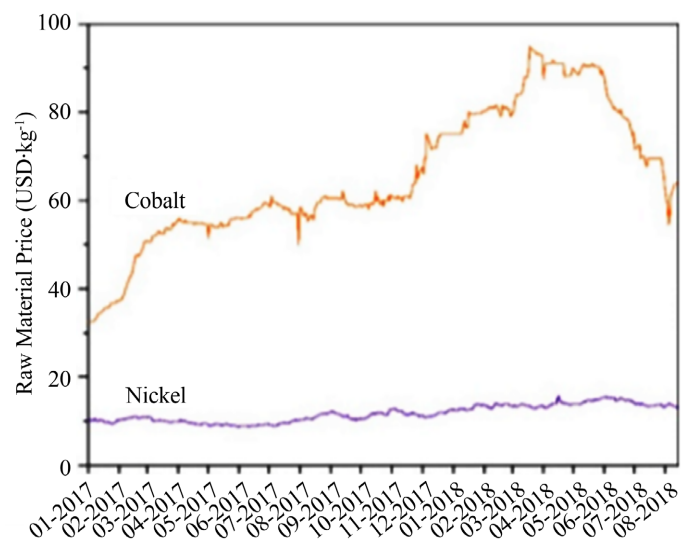

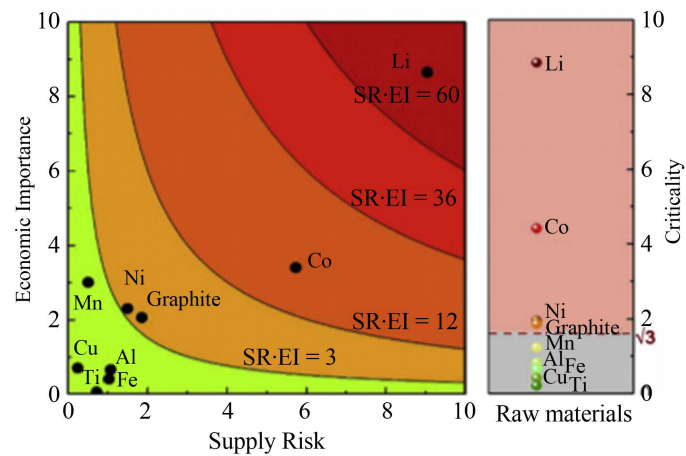Figure 1. Cobalt raw price fluctuations compared to nickel. Source: [8].

Figure 2. Economic importance vs supply risks of key LIB materials. Source: [9].

This increase in production will also increase the amount of scrap cathode material, which is projected to be approximately 275.01 - 391.83 kt in 2025 [9]. Over the course of the next 10 - 15 years as the initial wave of EV batteries reach their end life, either effective methods of EV battery recycling need to be met or new compositions of the cathode material must be realized. Some of the challenges that must be met in the next 10 - 15 years include:

1) Creating an effective recycling process;
2) Training more skilled workers;
3) Reducing the hazards to those working in the recycling plant;
4) Lessening variability in various car manufacturer power trains;
5) Developing Artificial Intelligence Algorithms which can be utilized to standardize the recycling processes [8].

2.3. Hybrid Energy Storage

Hybrid energy storage is capable of creating longer life and higher power energy storage solutions when paired with micro-grids. Specifically, the goal has been to utilize an algorithm that maximizes the utilization of high-power energy storage devices and minimizes the cycles of the batteries [10]. The main issue with these types of systems is that the initial cost is high enough for many to make the up-front investment, and although the extended life of the system could offset the cost, the time it takes to regain the initial investment is much longer. When looking at the long-term consequences of these systems, it is easy to understand the promise that they provide for next generation micro-grid energy storage, but the investment needs to be in place to reduce the up-front cost of these systems greatly.

One type of high-power, low-energy density storage device that can be utilized in these types of energy storage systems is a supercapacitor. Supercapacitors are defined as "electrochemical capacitors that lie between dielectric capacitors and batteries, and store large amounts of charge similar to batteries. Their design architecture involves two electrodes separated by an electrolyte and a separator

to keep the electrodes from shorting" [11]. Supercapacitors have an unusually high-power density, which is about 2 - 3 orders of magnitude more than a battery and is about 10,000 W/Kg [11]. Because of their high charge/discharge speeds, they can move large amounts of electrons over relatively small periods of time. The other key attribute of supercapacitors is their superior life cycles with very little energy density degradation, which is expected to be around several 100,000 cycles [11]. Because of this, a portion of the initial cost of these systems can be made up over time due to the fact that the high number of available cycles will decrease the cost/cycle. However, when comparing the cost per cycle of the supercapacitor to that of the battery, the supercapacitor has a significant draw back. While the supercapacitor cost per cycle lies around $0.20, the LIB cost per cycle is about $0.04.

The next type of high-power, low-energy density system that can be utilized in these types of systems is a flywheel. Flywheels work through a conversion of electrical energy into mechanical energy by sending an alternating signal through coils to push a wheel around, which is connected to the magnets. The energy stored in these types of systems is a function of both angular velocity and mass and when the stored energy is converted back to electrical energy, the process is reversed wherein the magnets create current in the coil, and that power-er is then sent to the system load [11]. The key factors for commercial availability of these energy storage systems are very similar to those of supercapacitors. They are known to have high-cycle lives and provide high amounts of power, but their cost per kWh is not economically feasible, being around 5000 Dollars/kWh. Nevertheless, they have very similar cycle lives as the supercapacitor; therefore, their cost per kWh per cycle is down to about $0.05, which is far more competitive to the price of LIBs.

3. Cost Analysis

3.1. Methodology

In this cost analysis, a comparison between hybrid energy storage and traditional battery-only energy storage is made. The first step in this process is to compare the total cost of the two system types. Based on the literature review, the expectation is that the cost of hybrid energy storage will far exceed that of traditional energy storage. Once this realization is confirmed, the second step is to use MATLAB's mixed-integer-linear program to optimize a selected tariff structure and to deduce if money can be saved by utilizing the increase power capabilities of hybrid energy storage.

The following information characterizes the MATLAB algorithm [12]:

Function Inputs:

- PV power profiles: p_pv;
- Load power profile: p_load;
- Residential Time of Use (TOU) Rate: RTP;

Function Outputs:

- Daily utility cost: Objective;
- Battery charge/discharge power: Bat_ans;
- Hybrid storage charge/discharge power: Hyb_ans;
- Combined hybrid and battery charge/discharge power: tot_ans;
- Battery state of charge: bat_energy_state_ans;
- Hybrid storage state of charge: hyb_energy_state_ans;
- State of charge of full system: energy_state_ans.

Parameters:

- Time horizon size: time_hour = 24;
- Sampling time: samp_time = 1;
- Battery power (kW): bat_pow = 5.8;
- Hybrid Energy Power (kW): hyb_pow = 24;
- Precent of system battery storage: per_bat = 0.8;
- Percent of system hybrid storage: per_hyb = 0.2;
- Total energy of system: tot_eng = 45;
- Battery rated energy (kWh): bat_eng = per_bat * tot_eng;
- Hybrid rated energy: hyb_eng = per_hyb * tot_eng;
- Max number of daily cycles: max_cycles = 1;
- Charging efficiency: chrg_eff = 1;
- Discharging efficiency: dis_chrg_eff = 1;
- Battery energy at start of simulation: int_energy_bat = bat_eng * 0.5;
- Hybrid energy at start of simulation: int_energy_hyb = hyb_eng * 0.5;
- Rated house permissible service size: serv_size = 24;
- Low bound of SOC at end of cycle: soc_fin_l = 0.4;
- Upper bound of SOC at end of cycle: soc_fin_u = 0.6.

Variables:

- p_bat_char: Power of battery charging;
- Power of battery discharging: p_bat_dis;
- Power of hybrid energy charging: p_hyb_char;
- Power of hybrid energy discharging: p_hyb_dis;
- Binary value for battery charging: u_bat;
- Binary value for hybrid charging: u_hyb;
- State of charge of battery: soc_bat;
- State of charge of charge of hybrid system: soc_hyb;
- Power relative to the grid: Pg;
- Charge and discharge power of battery: bat;
- Charge and discharge power of hybrid system: hyb;
- Defining number of cycles: cycles.

Constraints:

Final State of Charge Range:

$$\text{soc\_fin\_l} \leq \text{soc}(1, 24) \leq \text{soc\_fin\_u}$$

Battery Charging:

$$\text{zero}(1, 24) \leq \text{p\_bat\_char} * \text{chag\_eff} \leq \text{bat\_pow} * \text{u\_bat}$$

Battery Discharging:

$$-\text{bat\_pow} * (1 - \text{u\_bat}) \leq \frac{\text{p\_bat\_dis}}{\text{dis\_char\_eff}} \leq \text{zeros}(1, 24)$$

Hybrid Energy Charging:

$$\text{zeros}(1, 24) \leq \text{p\_hyb\_char} * \text{chrg\_eff} \leq \text{hyb\_pow} * \text{u\_hyb}$$

Hybrid Energy Discharging:

$$-\text{hyb\_pow} * (1 - \text{u\_hyb}) \leq \frac{\text{p\_hyb\_dis}}{\text{dis\_char\_eff}} \leq \text{zeros}(1, 24)$$

Battery SOC:

$$0.2 * \text{one}(1, 24) \leq \text{soc\_bat} \leq \text{ones}(1, 24)$$

Hybrid SOC:

$$\text{zeros}(1, 24) \leq \text{soc\_hyb} \leq \text{ones}(1, 24)$$

Utility Power:

$$-0.8 * \text{serv\_size} \leq \text{Pg} \leq 0.8 * \text{serv\_size}$$

Battery Cycle:

$$\text{cycles}(1, 24) \leq \text{max\_cycles}$$

Governing Equations:

Battery SOC:

$$\text{soc\_bat}(k) = \text{soc\_bat}(k-1) + \frac{\text{p\_bat\_char}(k)}{\text{bat\_eng} * \text{chrg\_eff}} + \frac{\text{p\_bat\_dis}(k)}{\text{bat\_eng} * \text{dis\_chrg\_eff}} \tag{3.1}$$

Hybrid Energy SOC:

$$\text{soc\_hyb}(k) = \text{soc\_hyb}(k-1) + \frac{\text{p\_hyb\_char}(k)}{\text{hyb\_eng} * \text{chrg\_eff}} + \frac{\text{p\_hyb\_dis}(k)}{\text{hyb\_eng} * \text{dis\_chrg\_eff}} \tag{3.2}$$

Defining Number of Cycles:

$$\text{cycles}(k) = \text{cycles}(k-1) + 0.5 * \left(\frac{\text{p\_bat\_char}(k) * \text{chrg\_eff}}{\text{bat\_eng}} - \frac{\text{p\_bat\_dis}(k)}{\text{bat\_eng} * \text{dis\_chrg\_eff}} \right) \tag{3.3}$$

SOC of Entire Energy System:

$$\text{soc} = \text{soc\_bat} * \text{per\_bat} + \text{soc\_hyb} * \text{per\_hyd} \tag{3.4}$$

Combined Charge and Discharge Battery States:

$$\text{bat} = \text{p\_bat\_char} + \text{p\_bat\_dis} \tag{3.5}$$

Combined Charge and Discharge Hybrid States:

$$hyb = p\_hyb\_char + p\_hyb\_dis \tag{3.6}$$

Combined Charge and Discharge of Entire Energy System

$$tot_{pow} = bat + hyb \tag{3.7}$$

Total Grid Power

$$Pg = p\_load + bat + hyb - p\_pv \tag{3.8}$$

Cost for Each Hour of the Day

$$\cos t = Pg * RTP \tag{3.9}$$

Total Utility Cost for Simulated Day

$$Objective\_2 = sum(cost) \tag{3.10}$$

For this simulation, the following profiles must be generated: PV power profile, residential load profile, and a tariff structure to model. For consistency, the data was produced to be representative of a typical Los Angeles resident.

The PV profile was generated using the System Advisor Model (SAM) software for the Los Angeles Area to create a yearly profile based on hourly time intervals for a 3 kWh array [13]. Once the data was retrieved, it was then processed in MATLAB to create monthly profiles, which can be seen in Figure 3.

Next, monthly load profiles are created in MATLAB, utilizing a yearlong dataset that profiles residential load data on an hourly basis, which was retrieved from the United States Department of Energy (DOE) [14]. These monthly load profiles can be seen in Figure 4.

The last set of data that is retrieved is the tariff structure that will be modeled for the simulation. For the purpose of this analysis, the basic structure of the Los Angeles Department of Water & Power (LADWP) was modeled [15]. For this data set, monthly profiles were created based on the base rates of the utility, but then these rates are multiplied by a ratio of on-peak to off-peak hours based on
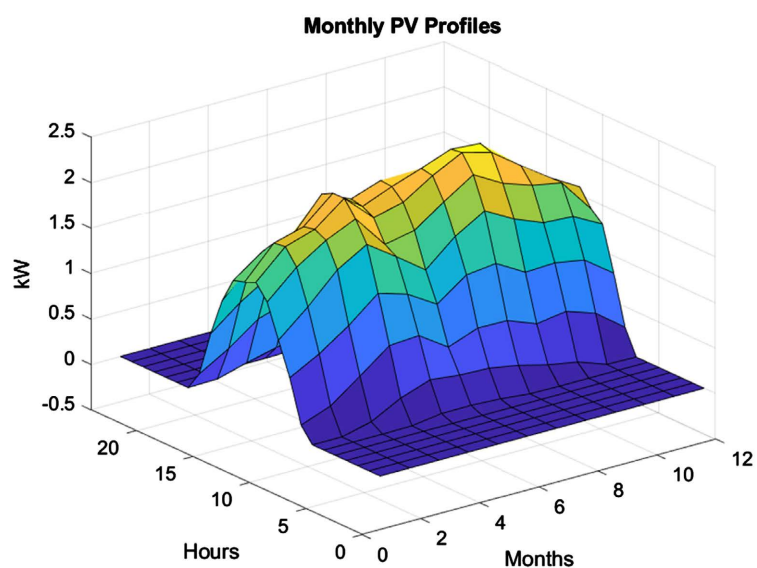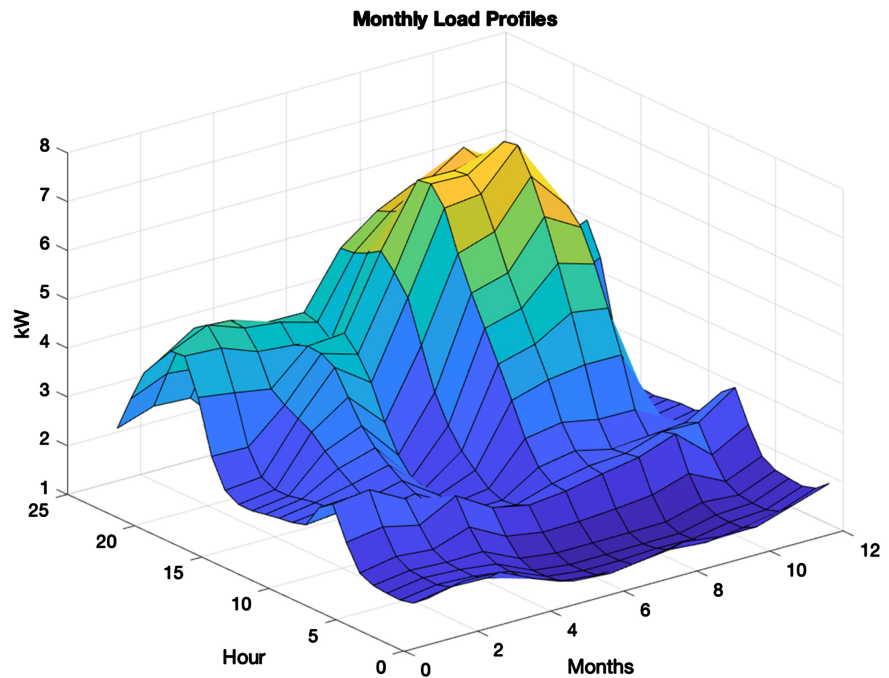

Figure 3. PV monthly profiles.

Figure 4. Residential load monthly profiles.

the peak-hours provided by the utility. This allows for the analysis of differences between on- and off-peak pricing, and an understanding of the role this data plays in total money saved by the hybrid energy storge system.

3.2. Results

As mentioned in the methodology section of the cost analysis, the first step involved creating the initial investment cost of various home energy storage solutions, and **Figure 8** shows the battery-only option price.

Looking at **Figure 5**, some promising trends relating to the cost of home energy storage devices are observed. The first worth noting observation is that the initial cost of investment for reused LIBs is less than the cost of new LIBs at the current time. This could lead to a more economically viable solution for consumers to install these types of systems. However, more understanding is needed in this area as the lifetime of these batteries is significantly reduced, and as a result, they may not be able to regain the same amount of money over a shorter period of time.

The next observation that can be made from **Figure 6** is that the initial cost of home energy storage should be expected to decrease continuously into the year 2030. This is based on the assumption that the NMC cathode compositions will continue to improve in electro-chemical performance over time, and the decreased material cost will be beneficial to the consumer. The other factor in the assessment is the promise of decreased prices and increased performance with the utilization of silicon-based anodes, as that is the option that is projected to provide the cheapest consumer pricing.
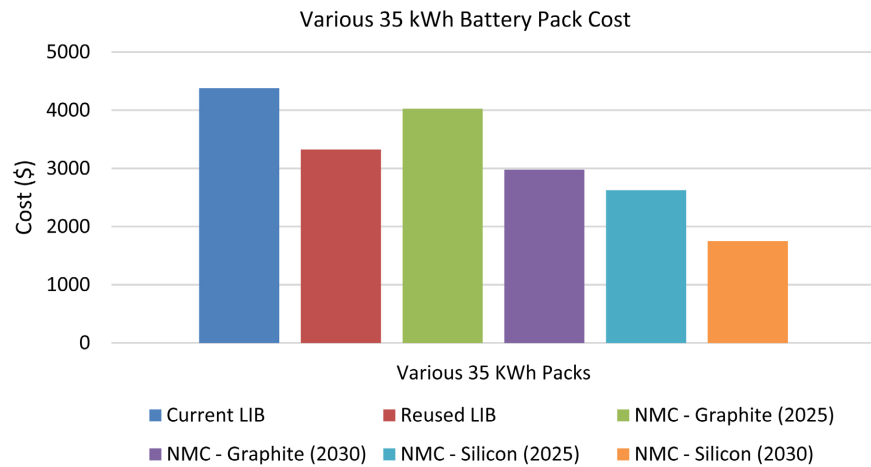
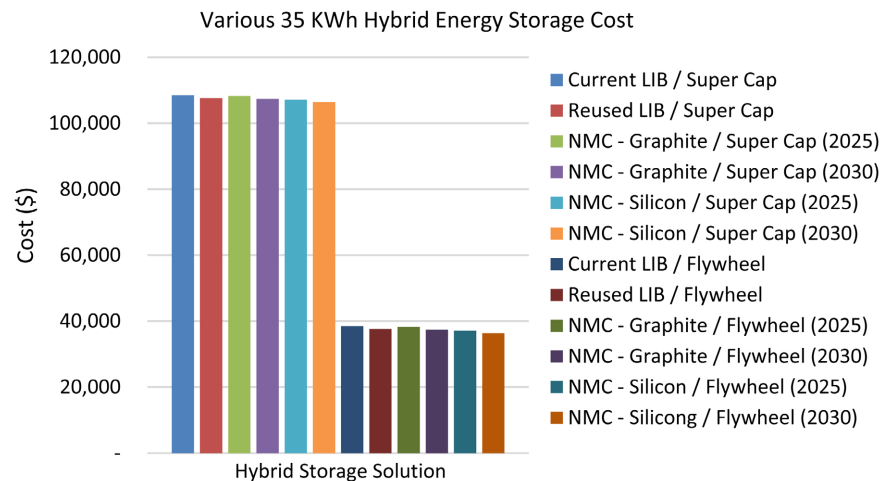**Figure 5.** Cost of various 35 kWh battery packs.

Figure 6. Cost of various 35 kWh hybrid energy storage solutions.

Next, **Figure 9** shows the initial cost of investment of various hybrid energy storage solutions.

As **Figure 6** shows, the initial cost of investment for these types of energy solutions would outprice the average consumer. Looking at the various combinations, the cost of the supercapacitor-based hybrid energy solutions is roughly triple the cost of those that utilize flywheels. Nevertheless, more research is necessary in both areas to continue to improve the options available in the energy market. Another interesting point to note when viewing this graph is that the various battery compositions have a small effect on the overall price of the system. This is due to the high cost per kWh of the supercapacitor and flywheels when compared to the various battery options.

Next, a comparison of potential daily savings of hybrid energy storage systems to traditional battery energy storage is made to see if the extra power can be leveraged to decrease utility cost. To accomplish this task, mixed-integer-linear program is utilized in MATLAB to optimize a selected tariff structure. An objective function that defines the total daily cost of hybrid energy storage and

another objective that defines the daily cost battery-only energy storage is run and the absolute value of the difference is defined as the total daily savings.

In reference to **Figure 7**, the daily savings generated from the hybrid energy storage system is displayed. For the tariff ratio of 1.0, the saving is the same for both 45 kWh and 35 kWh systems. This is due to the fact that the tariff structure is consistent for the entire days' simulation. Because of this, there are no on-peak hours that can be taken advantage of, to generate cost savings. However, this does not hold true for the 1.5 and 2.0 tariff ratios. This is because the varying cost structure of the tariff rates can be taken advantage of and leads to greater cost savings. As the tariff ratios and total energy of the system increase, so does the amount of money saved increase.

Viewing **Figures 8-11**, it is observed that the battery-only energy storage system and the hybrid energy storage system have very different patterns in regard
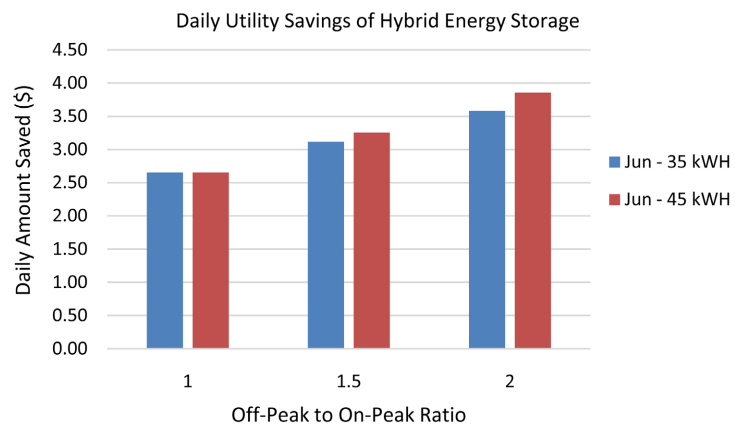

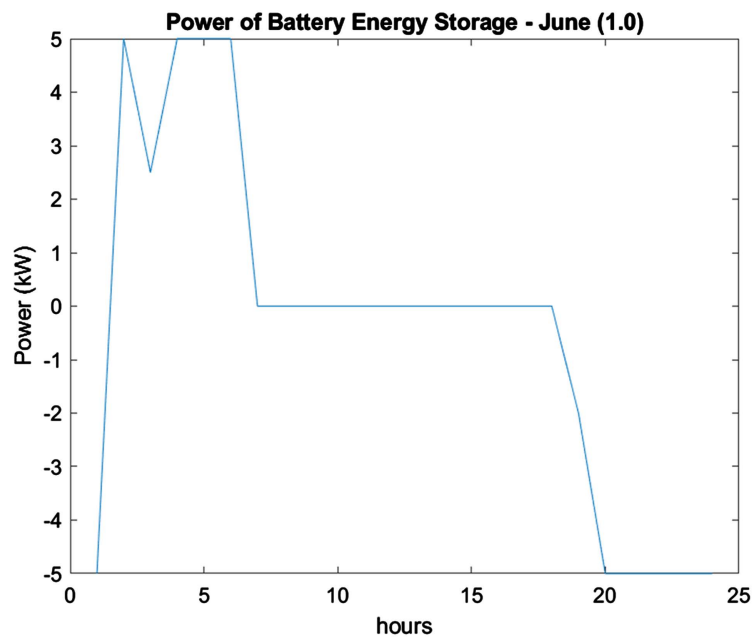**Figure 7.** Daily saving generated by hybrid energy storage.

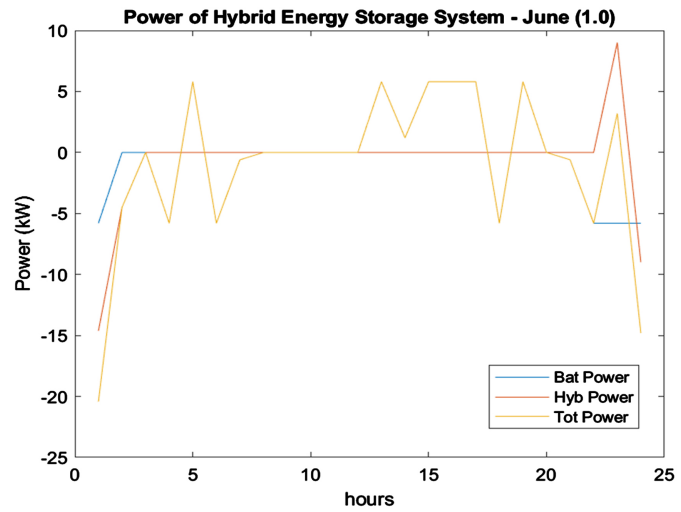**Figure 8.** Charge/discharge power—battery-only energy storage system.

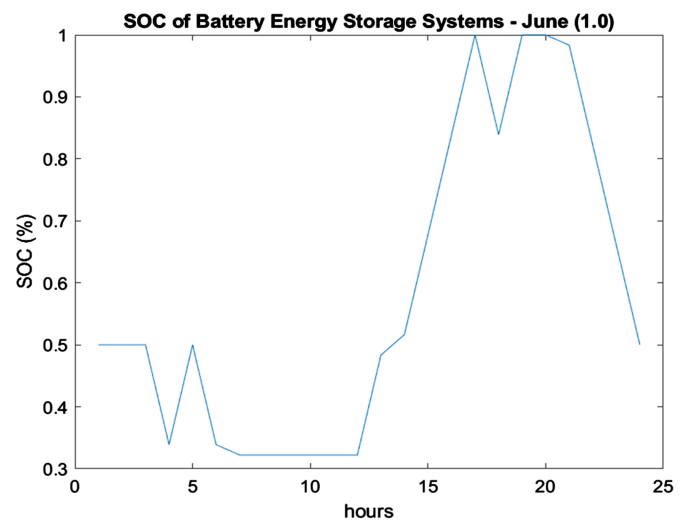**Figure 9.** Charge/discharge power—hybrid energy storage system.

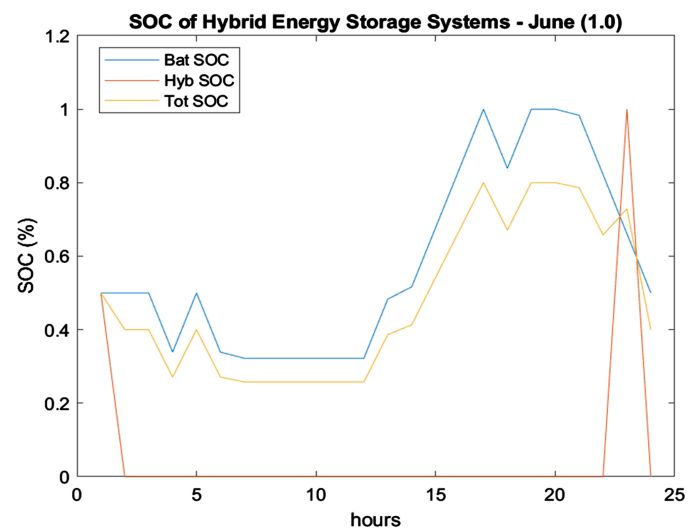**Figure 10.** State of charge—battery-only energy storage system.

Figure 11. State of charge—hybrid energy storage system.

to their charge and discharge power, but when viewing the SOC of both systems, the total SOC of the hybrid system changes very similar to that of the battery-only system. This trend makes sense due to there being no advantage to scenarios with a tariff ratio of 1.0 and this shows that the money made at this rate structure comes specifically from the end SOC being less than the start SOC. This means that the money made was strictly from selling back the energy from that the simulation began with.

Reviewing Figures 12-15, it is observed that with tariff ratio greater than one, the profiles of both battery-only and hybrid energy storage systems become more dynamic to decrease the cost saved and match the rate structure. In this scenario, the money is not only made by selling back the energy that was started with, but also by taking advantage of the changing rate structure throughout the simulated day.
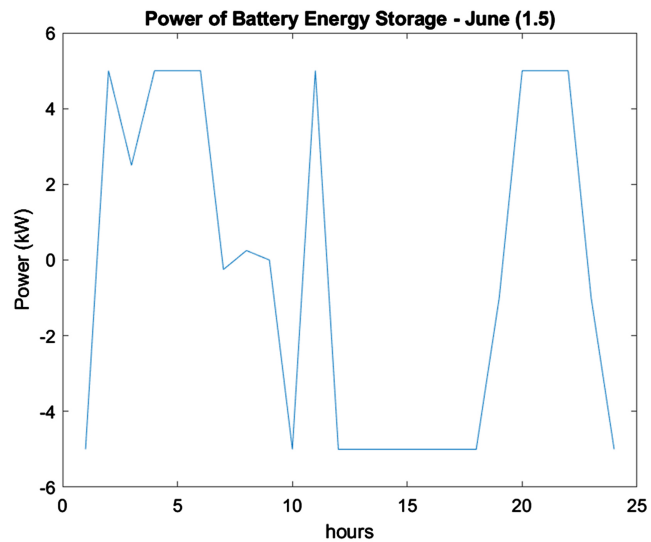

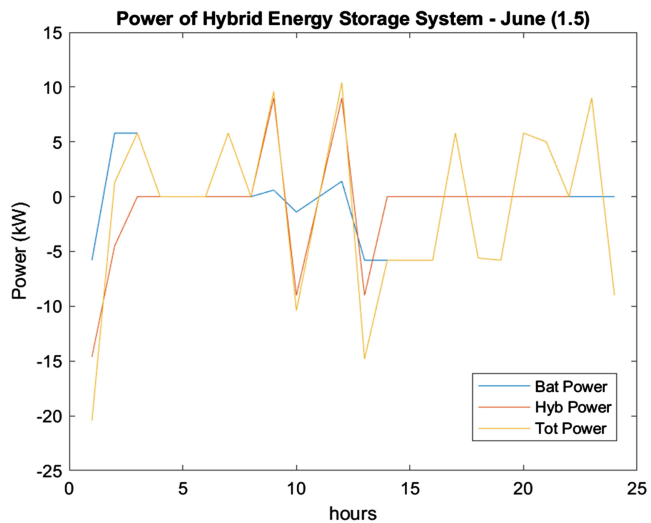**Figure 12.** Charge/discharge power—battery-only energy storage system.

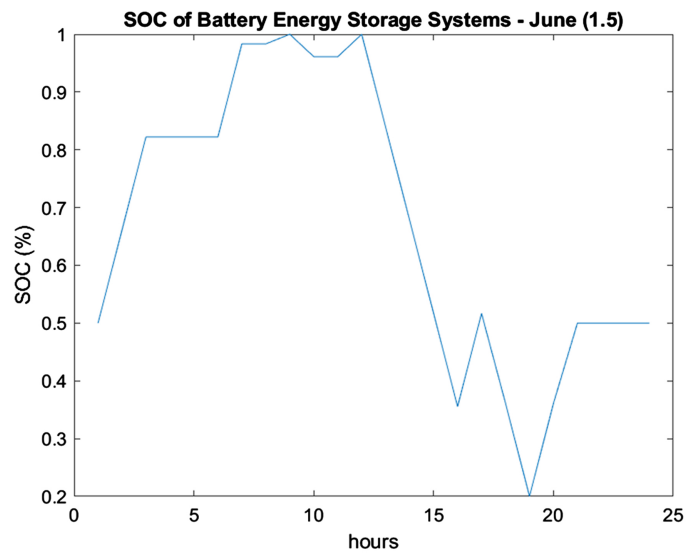**Figure 13.** Charge/discharge power—hybrid energy storage system.

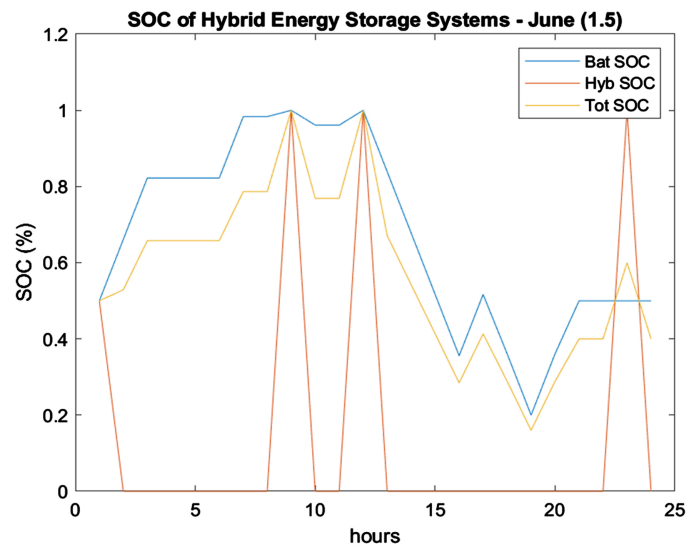**Figure 14.** State of charge—battery-only energy storage system.

Figure 15. State of charge—hybrid energy storage system.

4. Conclusions

Continuous development of the energy infrastructure is fundamental not only to the progress of the USA but also to providing energy solutions to developing nations, which will continue to be of importance well into the 21st century. One key approach to making this goal a reality is to continue fundamental battery and hybrid energy research, but additionally, there should always be a focus on the economic viability of these technologies and the impact that they will have on the final consumer. The conclusions drawn from this analysis suggest that in the near-term, home energy storage will begin to make more sense than utility-scale energy storage. This is mainly due to emerging battery compositions that correlate to decreased costs for the consumer. It is expected that when the initial investment of micro-grid energy storage becomes small enough to make

utility-scale energy obsolete, this is going to be the point when we can expect the transition to take place. The analysis shows that this phase will be arriving soon, but until then, governments can help propel society into the next phase of residential and commercial energy utilization with infrastructure investments to ease the financial burden on the average consumer.

Also, the conclusion is drawn that the decreased prices of either flywheels or supercapacitors could lead to utility cost-saving if the initial investment is not too big. As with traditional energy storage, such as batteries, increased development of these technologies will help to produce a more dynamic and consumer-friendly energy infrastructure. Future work into the viability of more robust algorithms such as Proximal Policy Optimization, which is able to navigate more generalizable scenarios, is key in the optimization of emerging energy storage and distribution technologies to the benefit of consumers.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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