Using Second-Use Electric Vehicle batteries to replace polluting peaker plants

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Introduction

Peaker Plants are those power plants which run only when the demand for electricity crosses a certain base load[1]. As these power plants are used occasionally, the cost of operating them is much higher than the normal power plants, which are operated continuously. The time of operation of peaker plants depends on the location of the plant. In case the plant is located in a region of lower temperatures, the peak might occur during early hours of the morning. However, if the temperatures are considerable high, the peak could occur in later evenings. Thus, operating periods of these peaker plants have a spatial variability and do not have a standard period of operation.

Traditionally, peaking power plants are run on non-renewable sources such as coal or natural gas. Apart from fossil fuels, hydropower could also be integrated into the power generation system[2]. Although these plants serve a noble purpose of providing a supporting hand to mainstream power plants in cases of high demand, the feasibility of operating such a power plant has more negatives to it than its positives.

This project aims to bring focus to the problem of operating and constructing newer peaking power plants, and explores alternatives to the using peaker plants, mainly through stationary ESS (Energy Storage Systems). The focus of the implementation is directed towards using Second Use Batteries from PEVs (Plug-in Electric Vehicles) and hybrid electric vehicles as energy storage to address the problem of peak load demand.

Shortcomings of Peaking Power Plants

Operating a peaker plant is very expensive, let alone being profitable. There are more than 1000 peaker plants which are currently operating in the United States, with the top 10 metropolitan regions accounting to around 20% of the total number of plants accounting to 60 gigawatt source of emissions[3]. As peaking

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[1] Wikipedia: Peaking Power Plants

[2] Wijesuriya, S. (2020). The “Peakers”: The role of peaking power plants and their relevance today. Retrieved from SciencePolicy circle: https://www.sciencepolicycircle.org/38-the-peakers-the-role-of-peaking-power-plants-and-their-relevance-today

[3] Phase out Peakers. Retrieved from CleanEnergy Group: https://www.cleanegroup.org/ceg-projects/phase-out-peakers/

plants operate occasionally, they lead to a multi-fold higher price per kWh, which causes a burden to the tax payers. Based on the high operating cost of such plants, construction of new peaker plants cannot be justified, from an economic point of view. For instance, the peaker plants in New York cost more than 1300% than the average cost of electricity[4].

Apart from the economic disadvantages, the peaker plants also contribute to the emissions in the environment closer to their location. These plants emit harmful pollutants such as fine particulate matter, nitrogen oxides and sulfur dioxide leading to health problems for the surrounding communities, especially those of low income neighborhoods[5].

It is thus imperative to look out for alternative options to tackle these problems. Stationary energy storage comes up as a good solution to integrate it with renewable sources of energy. Moreover, the rising demand for electric vehicles could provide impetus to using the retired electric vehicle batteries, integrated to the microgrid, thereby helping save a mammoth amount of costs and also proving beneficial to the environment.

Analysis of Use-Cases in United States

Replacement of peaker plants would involve bringing in a new type of energy source in place. Stationary Energy Storage Systems seem to be the best option, which provides a cheaper and modular solution. As per the reports of PSE[6], nine states in the USA were identified as use-cases which could provide good opportunities for primary candidates as peaker plant replacements.

Table 1: Summary of nine key states ideal for peaker plant replacement[6]

State	Number of peaker plants	Targets
Arizona	17	As per the State Policy, a target of 15% energy from renewables is set, of which a third should constitute of distributed energy sources. Also, the state aims at 50% reduction in greenhouse gases below 2000 levels, by 2040.
California	80	Although the long-term goal is to achieve 80% reduction in greenhouse gas emissions below 1900 levels by 2050 and a full carbon neutrality by 2045, the current aim is to phase out once-

[4] Phase out Peakers. Retrieved from CleanEnergy Group: https://www.cleanegroup.org/ceg-projects/phase-out-peakers/
[5] Ramirez, R. (2020, 05 19). The Drive to Replace Summer-Only ‘Peaker’ Power Plants. Retrieved from Wired: https://www.wired.com/story/the-drive-to-replace-summer-only-peaker-power-plants/
[6] PSE. (2020). Energy Storage Peaker Plant Replacement Project. Retrieved from PSE: https://www.psehealthyenergy.org/our-work/energy-storage-peaker-plant-replacement-project

		through cooling power plants (most of which are peaking plants) by 2030.
Florida	35	Florida has limited policies in support of renewable energy. However, some major companies are in favor of implementing energy grid strategies. For instance, Florida Power & Light plans to bring a 409 megawatt battery storage system in 2021
Massachusetts	23	The state policy targets a 35% of electricity from renewable energy, especially through solar energy by 2030. In addition, it aims for 80 % reduction in greenhouse gas emissions below 1990 levels.
Nevada	5	Nevada aims to have a 50% renewable energy generated electricity with a 45% below 2005 levels for greenhouse gas emissions by 2030. The state has set an ambitious target of 100% carbon-free electricity by 2050.
New Jersey	15	The state policy has a target of 80% percent reduction in greenhouse gases by 2006 levels by 2050. The shorter aim is to ensure 50% renewable electricity by 2030.
New Mexico	11	New Mexico targets 100% electricity from zero carbon sources by 2045. Moreover, it aims to reduce 45% of greenhouse emissions of 2005 levels.
New York	50	Although New York aims to have 70% of renewable energy sourced electricity by 2030, whereas a full carbon neutrality by 2050. Further, it also aims to reduce 85% greenhouse gas emissions by 1990 levels by 2050.
Texas	65	Although Texas doesn't have any fixed targets, multiple initiatives have been put forth to promote energy storage.

A common point of inference from the use-cases of these 9 states is that most states are looking forward to curb carbon and greenhouse emissions, while also promoting stationary energy storage.

Batteries prove to be the best alternative for peaker plants with the primary advantage being it's cheaper cost of installation and operation. In addition to that, batteries provide a cleaner alternative in terms of reduced environmental harm and could also help reduce the cost of transmission by installing it near high demand areas[7]. As the batteries could be charged using renewable energy sources of energy, it could also help in achieving goals set by the state policies. Further improvements to reduce costs and utilize available resources could be through second-use batteries, procured from early discharge of PEVs (Plug-in electric vehicles) or hybrid electric vehicles. Using second-use batteries as an alternative could further incentivize

[7] Newbery, C. (2018, 10 01). Energy Storage Poses a Growing Threat to Peaker Plants. Retrieved from Transform: https://www.ge.com/power/transform/article.transform.articles.2018.oct.storage-threat-to-peaker-plants

electric vehicles by lowering its operating costs. An increase in such modes of transport would lead to a substantial decrease in standard vehicular emissions.

Modeling of Second Use batteries to mimic Peaker Plant behavior

This section puts forth a modeling approach to estimate the amount of second-use batteries required in a grid to mimic peaker plant behavior. There are certain assumptions to the approach such as:

1. All second use batteries are assumed to be identical in nature and of similar capacity
2. The batteries in use are compatible with the energy grid installed
3. All batteries are retired at a fixed interval, that is when the battery performs at a certain capacity since its production

Assuming that l is the load requirement, with b as the base load. Thus, excess load, e is obtained as:

$e = l - b$ … (1)

In order to take into account the second-use battery behavior, three parameters are taken into account:

c : Working capacity fraction of the battery at which first-use is terminated

η : Efficiency of the battery

l_b : Load capacity of each battery

Thus, the capacity of the second-use battery during installation is:

$l_{sb} = c\eta l_b$ … (2)

The number of second-use battery equivalents is defined as:

$n_b = \frac{e}{l_{sb}}$ … (3)

From Equation (1) and (2), the second-use battery equivalents become:

$n_b = \left\lceil \frac{l-b}{c\eta l_b} \right\rceil$ … (4)

Using Equation (4), the number of second-use battery equivalents can be thus, estimated.

Modeling Second-use battery equivalents for New York City

As per Clean Energy Group's report[8], New York's peaker plants generate one of the most polluted and expensive electricity during peak load. Thus, the use case under consideration was that of NYC (New York City). As per the data obtained from NYISO[9], electricity load data for January 2020 to July 2020

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[8] Phase out Peakers. Retrieved from CleanEnergy Group: https://www.cleanegroup.org/ceg-projects/phase-out-peakers/

[9] NYISO (New York Independent System Operator). Retrieved from Energy Online: http://www.energyonline.com/Data/GenericData.aspx?DataId=13

(Current date as of analysis) was extracted and used for modeling. The data was averaged for the entire duration of the month, amounting to a single value every hour for every month for New York City.

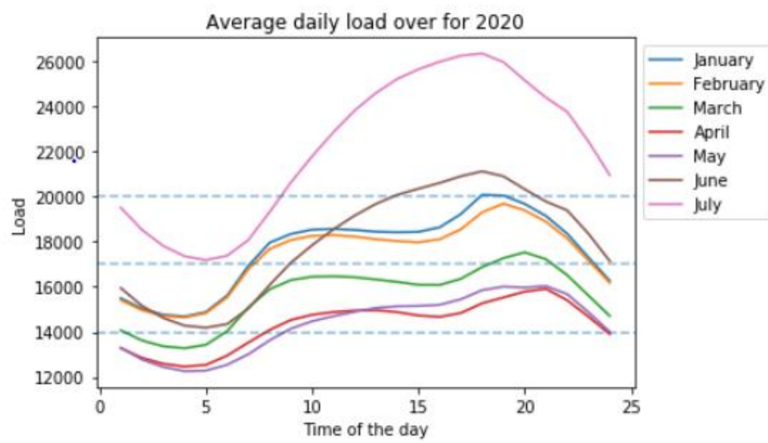

Figure 1: Average daily load (over month) for New York City from January 2020 to July 2020 over 24 hours of the day

The base demand for New York City was varied from 14000 to 20000 MWh (assumed units) and any load above that was assumed to be excess. Additional parameters for equation (2) were fixed as follows:

c=0.7 (Batteries are retired when they reach 70% of their original capacity)

η=0.8 (Efficiency of batteries was fixed at 80%)

$l_b = 85kWh$ (Capacity of standard battery for Tesla Model S)

Using Equation (4), number of second-use battery equivalents for every month and every period of the day were estimated.

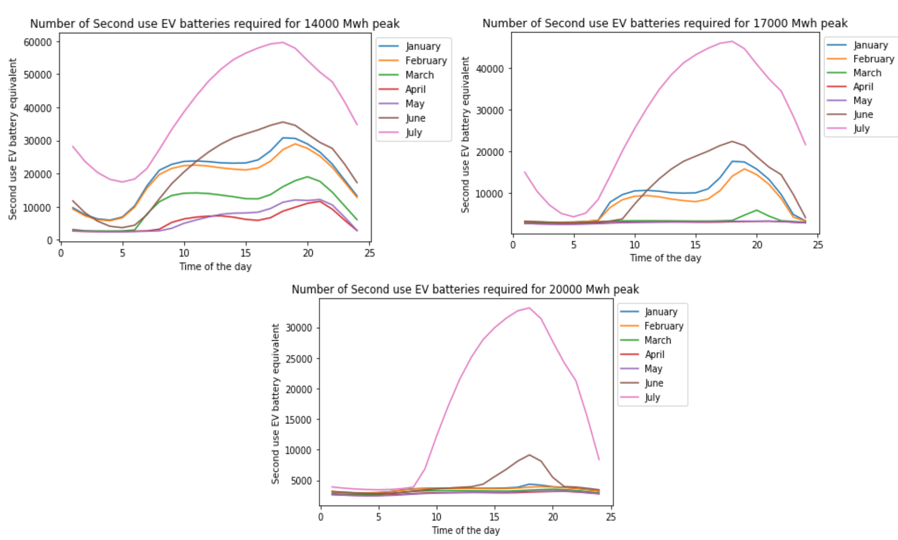

Figure 2: Visualizing trend of second-use batteries required for the grid installation over time of the day for each month with different base loads (14000, 17000, and 20000 MWh)

From Figure 2: Visualizing trend of second-use batteries required for the grid installation over time of the day for each month with different base loads (14000, 17000, and 20000 MWh) it can be observed that, as the base load demand increases, lesser number of battery equivalents are required. This comes from intuition that as the capacity of normal power plants to cater the demand increases, lower will be the peak requirement.

Using this methodology, the maximum amount of batteries required per month of the year (2020) was evaluated, and tabulated. From Table 2, it can be observed that the trend for number of second-use batteries which could mimic the peaker plant capacity at more than base demand depends on the month (season plays an important role) and

Table 2: Maximum second-use battery equivalents per month for different peak loads (14000, 17000, and 20000)

	January	February	March	April	May	June	July
14000	127675	119393	74124	40168	42795	149489	259150
17000	64649	56367	11098	0	0	86463	196124
20000	1624	0	0	0	0	23438	133099

The data is plotted in Figure 3 for better visualization. It can be observed that a similar trend is followed in case of the three lines. As the base load is increased, peak demand is required on a lower number of instances and thus, overall, lesser number of second use batteries are required. The trend indicates that for the month of July 2020, a greater number of second-use battery equivalents were required as opposed to the lowest during the period of April and May 2020. Seasonal fluctuations in the demand for electricity, thus influences the number of second use batteries which could replicate the same.

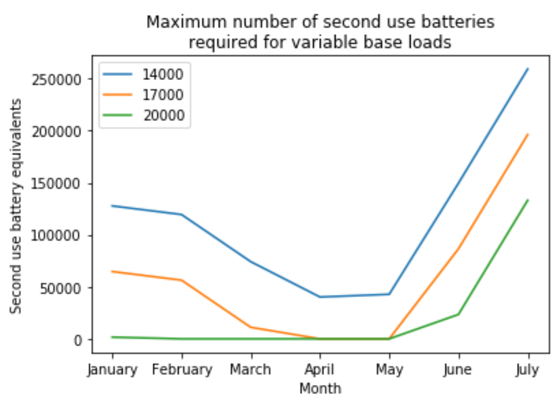

Figure 3: Maximum second use batteries for every month of 2020 (upto July) for variable base loads

Further, this methodology can be replicated to multiple areas, if more data is available. The code for the entire modeling is made available publicly[10].

[10] Code repository: https://github.com/yashgokhale/Miscellaneous/tree/master/battery_modeling

Health and Safety Review

There are multiple aspects to be considered while replacing the existing power plants with stationary energy storage system. Li-ion battery with a Prismatic architecture was chosen as the basis for the study. In order to mitigate the risks associated with using stationary storage, the review consists of three aspects:

1. Identifying potential risks associated with peaker plants (power plants in general)
2. Identifying potential risks associated with stationary energy storage
3. Eliminating existing risks posed by power plants with the emerging risks due to energy storage in order to encourage replacement

Peaker Plants Safety Review

The most critical point of consideration is that a power plant (coal-fired or natural-gas fired) poses risks to the workers through multiple modes, the most striking being through electric short circuits, fires, gas leakage or spilling of hazardous materials[11].

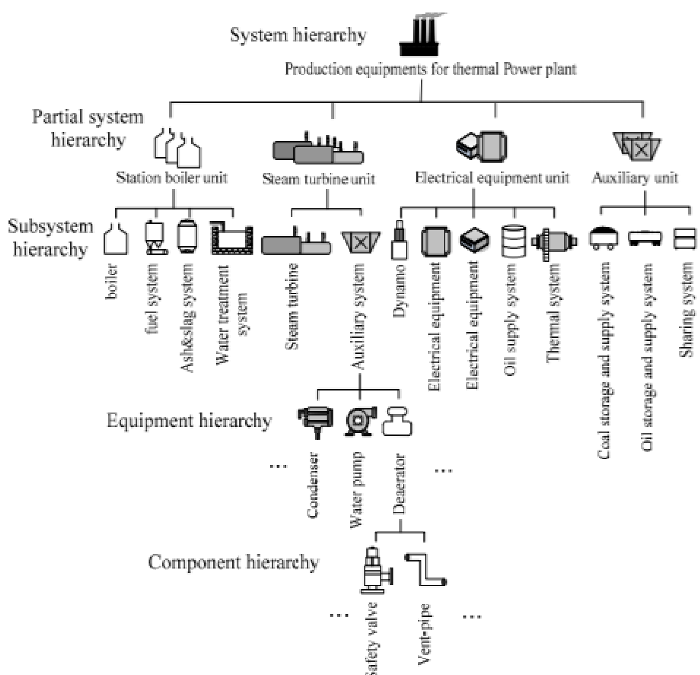

Figure 4: A sample graph for SDG-HAZOP method[11]

[11] Zhang, C., Zhang, P., Yang, Z., & Song, L. (2009). Safety Assessment Modeling for Thermal Power Plants Using Hierarchical SDG-HAZOP Method. 2009 IEEE International Conference on Intelligent Computing and Intelligent Systems. IEEE.

Based on the SDG-HAZOP method proposed by Zhang et al[11] , the study of power plants is carried out using a combination of using a network graph (SDG) and HAZOP (Hazard and Operability Studies). The method plans to lower the complexity of the multiple units of plants by defining a hierarchal structure of different equipment used in the unit. Upon defining the structure, pain points for safety at each individual location in the network graph is identified and then acted upon. As shown in the Figure 4, the graph follows a descending structure in terms of composition of a power plant. For a standard coal/natural gas operated power plant, major units such as the boiler unit, turbine unit, electrical unit, etc. are considered in depth with a focus on multiple sub-units used in the operation. Based on the same structure, this section aims to follow a similar approach for the replacement of power plants with stationary storage. The entire renewable energy operated power plant will be assessed for potential areas of risk, broken down into sub-domains and eliminating instances of sufficient doubt, by defining proper safety measures.

Stationary Energy Storage Systems (EES) Review

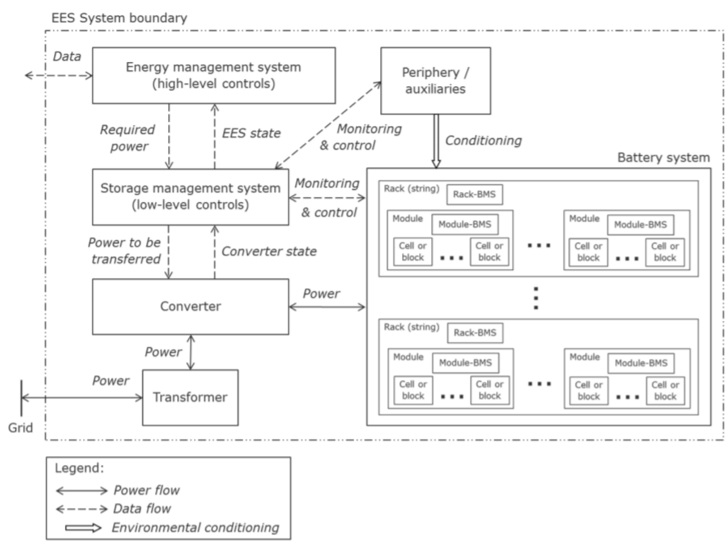

Figure 5: General schematic of Li-ion battery system[12]

In this case, the Li-ion battery has been chosen to be used, which is an electro-chemical source of energy. This energy storage is planned to be operated at moderate temperatures with additional structuring in case of extreme conditions.

[12] DNVGL-RP-0043. (2017). Safety, operation and performance of grid-connected energy storage systems. DNVGL.

Certain key pain points have been identified with their proposed solutions:

Table 3: Identifying pain points with their proposed solutions

Pain Point	Proposed Solution
Temperature fluctuations Thermal runaway might result in self-ignition and explosion	The external temperature of batteries must be constantly monitored using temperature indicators, also with a system alerting the plant operators. In order to monitor the internal temperature of the batteries, contactless approach can be implemented as put forth by Ma et al[13]. Predicting the internal temperature using modeling simulation and electrochemical impedance can be used.
Ventilation Uncontrolled flue-gases might result in degradation of battery and fire in certain cases.	The lower explosion limit (LEL) of the air should be monitored periodically using sensors to ensure that gases are allowed to escape the battery system without accumulation[13].
Fire There are multiple causes for fire in batteries: Li-ion chemistries are highly reactive and react to fire quickly	Certain measures to consider: Fire extinguisher is present in the plant at multiple sites to tackle unexpected cases of fire. Shutdown procedures for the plant must have proper provision for inadvertent fire and explosion.
Leakage There might be a leakage in the Li-ion batteries due to the electrolyte fluid	It is necessary that adsorption of liquid residue with an adapted adsorbent is necessary. In addition to that, any operating personnel in contact with the leakage should be catered with medical care urgently.

Summary

As the world is slowly moving towards cleaner technologies for energy and most ruling bodies are pushing for reduction in emissions, getting away with the polluting peaker plants seem to be a viable solution and replacing it with a stationary storage system serves the purpose. To cater to the growing energy demand, USA needs to add around 20 GW of peaking capacity to its grid over the next 10 years, with around 60%

[13] Ma, S., Jiang, M., Tao, P., Song, C., Wu, J., Wang, J., . . . Shang, W. (2018, 12). Temperature effect and thermal impact in lithium-ion batteries: A review. Progress in Natural Science: Materials International, 28(6), 653-666. doi:https://doi.org/10.1016/j.pnsc.2018.11.002

of it to be installed between 2023 and 2027[14]. The high operating cost and much higher cost of electricity produced would serve as deterrents to building new peaking power plants. Thus, in order to cater to the rising demand, building robust ESS using batteries would work in favor, both economically and from an environmental standpoint. Also, using second use batteries serves as a viable purpose in lowering the cost of electric and hybrid vehicles, which in-turn help further towards lesser emissions. The optimum cell configuration (Li-ion Prismatic cells), is often used in electric vehicles and could thus, be used in energy storage systems upon retirement from its first use.

Overall, second use batteries showcase a great potential in being a key player to replace peaker plants and also as an alternative to new peaker plants being set up. Upon successful implementation of second use batteries in energy storage systems as a prototype for providing supply for peak load, similar implementations could be followed for generalizing the storage systems. Additional avenues into using second use batteries for electricity can also be explored through setting up such systems in regions with low income (around the world), promoting cheaper alternatives to first use batteries and cleaner alternatives to fossil fuel energy.

Future Scope of Work (In Progress)

1. Economic Modeling: Currently in its final stage, a complete economic analysis of second-use batteries to be integrated into the grid is in process. The study would enable determining the feasibility of commercializing the plan and amending certain factors
2. Process Simulation: Using COMSOL models for Li-ion batteries, a degradation model for Second Use EV batteries is to be determined so as to predict the life cycle of the batteries, thereby improving the estimation of second-use battery equivalents
3. Optimum battery type: Analysis of different types of battery chemistries and battery architecture is being analyzed to choose the optimum type and its operability over environmental conditions
4. Environmental Impact: Positive impact of using this strategy can be analyzed through certain cases in place.

[14] Newbery, C. (2018, 10 01). Energy Storage Poses a Growing Threat to Peaker Plants. Retrieved from Transform: https://www.ge.com/power/transform/article.transform.articles.2018.oct.storage-threat-to-peaker-plants