Vol 5 No 1 (2023) *e*-ISSN: 2682-8383

Journal of Engineering Technology and Applied Physics

# Feasibility of Use of Second Life Electrical Vehicle Batteries in Data Centres in Malaysia

Abdulla Mubaah and Siva Priya Thiagarajah*

*Faculty of Engineering, Multimedia University, Cyberjaya, Selangor, Malaysia.*

**Corresponding author:* siva.priya.thiagarajah@mmu.edu.my, *ORCiD:* 0000-0002-0024-7279

https://doi.org/10.33093/jetap.2023.5.1.2

*Manuscript Received: 13 September 2022, Accepted: 13 October 2022, Published: 15 March 2023*

***Abstract* - It is estimated that the cumulative of Electric Vehicles (EVs) will reach 85 million by 2030. EV batteries that have degraded to 80% of their initial capacity no longer provide the required efficiency for EV, resulting in an increasing amount of batteries being discarded and stored in warehouses instead of being recycled. The cost of this storage after its End of Life (EOL) adds to the initial cost of the EV. There is amounting environmental pressure to re-purpose these discarded batteries in other applications, such as energy arbitrage and peak shaving, such that the initial cost of the EV be reduced. This work presents a feasibility study that allows discarded EV batteries to be repurposed batteries to provide peak shaving in a mid-tier data centre with an area size of 465 m$^2$. A comparison of the cost during peak hours shows that the repurposed batteries can be used as a reliable power supply source to reduce the reliance of data centres on grid power during peak hours. Results showed that the use of these repurposed batteries also achieved a higher cost savings as compared to using brand new Lithium Ion battery over a period of 10 years. A reliability study also shows that the repurposed battery system and brand new battery system performs at par, when the data centre draws power from the grid during peak hours. The study concludes that power supply system in data centres that uses repurposed batteries to achieve peak shaving is a cost effective, green solution that should be implemented. In the larger picture, the reusability of the EV batteries is expected to reduce the initial price of the EV cars, allowing a larger market penetration and thus ensuring the sustainability of the EV car industry. Reusing the stored batteries also reduces environmental issues related to Lithium mining for brand new batteries, such as mining pollution and fresh water shortage.**

***Keywords—Peak Power Shaving, Repurposed Lithium Ion batteries, Operation Cost Reduction, Environmental Damage Reduction, Electrical Vehicle Industry Sustainability***

## I.INTRODUCTION

### *A. Electrical Vehicles Induced Waste*

Lithium-ion (Li-ion) batteries are widely used in energy storage due to its extremely large energy density good performance [1]. Li-ion batteries have and roundtrip efficiency of 85-95% and a lifetime of about 2000-3000 cycles (10-15 years) [2]. They are used in consumer electronics, battery electric vehicles (BEVs), plug-in electric vehicles (PHEVs), and hybrid electric vehicles (HEVs). In PHEVs and HEVs, Li-ion batteries are used as a total replacement or partial replacement for gasoline and combustion engines, making modern transport beneficial for the environment [3].

The transportation industry, with a rapid growth, is the second-largest energy consumer from carbon based sources, making it one of the main contributor of greenhouse effect accelerating carbon dioxide emissions. These concerns paved the way for the rapid commercialization different types of EVs on a global scale. A survey carried out by the International Energy Agency (IEA) showed that the number of EVs specially BEV and PHEV types have risen between 2013 to 2018. The May 2019 IEA report highlighted that around 5.1 million EV's were sold in 2018 globally, which is almost two-fold compared to the sales in 2017 [4].

Figure 1 shows a scenario in Germany, whereby the rapid growth of EVs will make available a total accumulative second life battery (SLB) of 100 GWh by 2030 [5]. Reports by Bloomberg [6] and Deloitte forecasts an increase of EV sales by 2030, with battery electric vehicles (BEVs) accounting for a 70% of the global EV market [7]. With such promising forecasts, an IdtechEx research expects that there will be over 6



Published by MMU PRESS. URL: https://journals.mmupress.com/index.php/jetap/index

million battery packs reaching its end-of-life (EOL) in electric vehicles by 2030 [8].

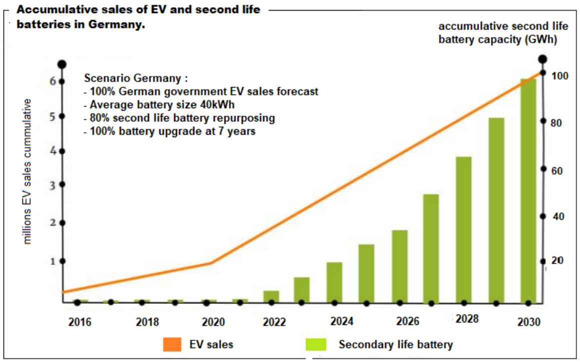


Fig. 1. Accumulated sales of EV and SLB [5].

Despite its many advantages to the EV industry, the battery needs to have efficiency levels of higher that 80%. Once the residual capacity of the EV battery falls below this threshold, the batteries are discarded. These discarded batteries are stored in warehouses for infinite time, as the cost of recycle is significantly higher. The increasing environmental concerns related to the number of discarded EV batteries has paved way for research in the re-purposing of EV batteries for other applications. One of the solutions by engineers and policymakers is utilising the used EV's battery in Energy Storage Systems (ESS) [9]. One specific application would be to use the repurposed battery as ESS in data centres. The growth of data centers around the world is leading to an increase in energy demand, which supplements for efficient energy storage solutions [10]. The retired batteries could have a second life in the data centers, connecting the automotive and the electricity sector. Thus, a technical and cost analysis on the feasibility of using the repurposed battery or second life electric vehicle battery (SLEVB) is needed in order to be used in energy storage in data centers.

### *B. Reliance of Data Centres on Electrical Grid Power*

A data centre typically consists of a (a) server farm, (b) power supply equipment, (c) backup generation, (d) energy storage, (e) heat and air flow system, (f) cooling system and (g) control and security systems [11] as shown in Fig. 2.

The energy consumed by a data centre can be generally categorized into two parts which is the IT equipment power usage (e.g., servers, networks, storage, etc.) and the infrastructure facilities power usage (e.g., cooling and power conditioning systems). [12]. The energy consumed by IT equipment and the infrastructure facilities depends on the design, size and the efficiency of the equipment. Infotech group has highlighted that the cooling infrastructure is the largest energy consumer in a typical data centre, consuming about 50% of the total energy, while servers and storage facilities consume about 26% of the energy consumption hierarchy [13]. However, these consumption rates may differ from data centre to data centre.

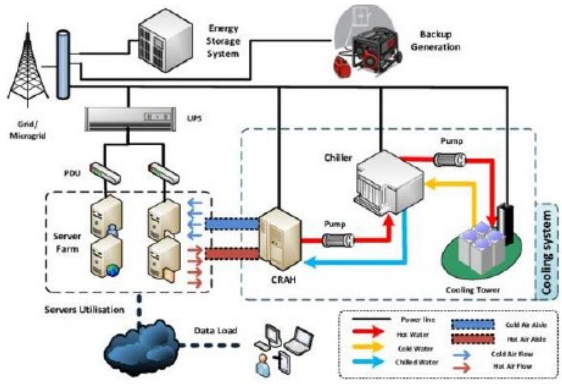


Fig. 2. Typical interconnection in a data centre [11].

### *C. Lifespan and Useful Life of Second Life Battery*

The parameters used to determine the quality and the useful life of the retired batteries are State of Charge (SoC), Depth of Discharge (DoD), number of cycles, battery chemistry, charge and cell temperature [14]. The study in [15] conducted a study with second life battery (SLB) comprising of nickel metal hydride battery (NiMH) and Li-Ion batteries in a grid system to estimate the lifespan of the battery using real DoD rates. The data from the study estimated that the SLB could last 6 years supporting 750 ancillary services and that the SLB was likely to support the energy management with a DoD of 50% for about 7 years. The study in [16] connected the impact of DoD on the lifespan of the battery using SLB, where DoDs with varying range of charge and discharge points were tested to determine the lifespan. The study done in [16] found that reducing the DOD from 80% to 50% increased the life span.

### *D. Economics of Second Life Battery*

Cost studies on the EVs price emphasised that the battery cost is a major contributor to the EV's high sales price [17]. As a result, car manufacturers are looking for alternate ways to cut down costs by repurposing the retired batteries returned by the car owners. Utilisation of these batteries could create great financial opportunities to EV owners, SLB users, battery re-purposing companies and battery recyclers [18]. While EV owners find value recovery from the returned batteries instead of storing them, the SLB users may experience lower cost in the establishing ESS as the SLB can be bought at a cheaper price than a brand new battery. Battery repurposing companies have a business model in retrieving, reorganizing, and repackaging of the discarded batteries. Corporate giants seeking to use SLB can upscale their corporate image as a green company, and in some countries, claim tax relief for actions towards reducing carbon footprints and environmental damages that are related to use of fossil fuel based grid power and other environmental damages related to lithium mining.

*E. Environmental Economics of Second Life Battery*

Second Life EV Battery (SLEVB) as an Energy Storage Systems (ESS) offers a cleaner and sustainable approach to tackle emissions and climate mitigation, primarily by eliminating the first life battery manufacturing for ESS usage. From a waste management perspective, reuse of EV battery is more favourable. In order to mine 1 tonne of Li-Ion a total of 750 tons of mineral rich brine is required [19] The process of refining and mining at this scale is very harmful to the ecosystem as well as the environment. However, by simply reiterating the old reuse concept, SLBs could reduce the global warming potential (GWP) and the Gross Energy Demand (GED) by 15-70% [20].

*F. The Right Time for Second Life Battery Usage Awareness in Malaysia*

According to Energy Commission of Malaysia, the major consumers of energy are the Commercial and Industrial (C&I) sector followed by the residential and transportation sector. The C&I sector faces expensive electricity bills due to energy consumption usage and the maximum demand. According to the National Renewable Energy Laboratory (NREL) maximum demand charges could account for 30% to 70% of the electricity bill [21]. Using practices such as smart grids and ESS, consumers can cut down running costs by storing energy during off peak hours and utilising the energy during peak hours of the day. Investing in a second life ESS would further reduce the costs incurred by the C&I sector.

A second reason to invest in second life ESS in a country like Malaysia, is because no ESS pilot projects have been set in place in the South East Asia region. Establishing a second life ESS would further enrich the studies on the effect of ambient temperature and climate conditions on the ageing and performance of the SLB. With no current study focusing on using SLB for peak shaving in tropical countries, a ESS with SLB in Malaysia would provide sufficient data for the potential second life application in tropical countries [21].

Several pilot projects on SLB installations have been carried out, ranging from several kWh to several MWh in terms of storage capacity. General Motors and ABB jointly developed an ESS using five used Chevrolet Volt batteries packaged in a modular unit that was capable of delivering 50 kWh of energy storage [22]. A 2MW/MWh large scale ESS was develop by Bosch, BMW and a power company named Vattenfall (Sweden) to support the electrical grid infrastructure in which BMWs Active E and i3s Li-Ion batteries were used [23]. Elverlingsen, a power station in Germany, has a total of 1920 SLB modules as an ESS that has an energy output of approximately 9.8 MWh. This ESS is used continuously to stabilise the power grid [24].

This paper aims to investigate the feasibility of using SLEVB as a power supply system for data centers in Malaysia. The proposed SLEVB system will be used to peak shave the power supply required from the grid that is supplied to these data centres. The reduced reliance of data centers on electrical grid is projected to reduce operator cost. The contribution of this paper is twofold: a comparison on the use of brand new Li-Ion battery versus the SLEVB. The study will show the results of a cost feasibility study using brand new Li-Ion battery, SLEVB and complete reliance on grid (no peak shaving).

## II. METHODOLOGY

The base model was designed in MATLAB SIMULINK to compare the effects of the brand new Li-Ion battery and the SLEVB to be used for peak power shaving in the data centre. A base model consisting of a 50 Ah battery pack was used to supply a constant load of 6 Ohm, whereby the load is connected to a constant voltage of 48 V. The load is switched between the battery and the constant voltage supply using a switch. The battery is connected to the load via a bidirectional DC-DC converter which have the capability of power flow in two directions, enabling the battery to be charged using the same voltage supply. The brand new battery pack parameters used in this study are those of the 18650 Li-ion 12 V 50 Ah Battery Pack [25]. The SLEVB was modelled by changing the parameters of the brand new battery, as shown in Table I, that shows the aging parameters that were applied to the battery pack. The model was aged to have a cycle life of 3000 cycles at the end of its 1st life with an internal resistance of 50 milli ohm. The model also was simulated to having a capacity of 40 Ah at its end of 1st life (brand new life).

Table I. Aging parameters used to simulate the SLEVB.

| | |
|---|---|
| Initial battery age (Equivalent full cycles) | 3000 |
| Ageing model sampling time (s) | 120 |
| Ambient temperature, $T_{a1}$ | 25°C |
| Ambient temperature, $T_{a2}$ | 40°C |
| Capacity of End of Life (EOL) (Ah) | 40 |
| Internal resistance at EOL (ohm) | 0.05 |
| Charge current (nominal, maximum) [$I_c$(A), $I_{c,max}$(A)] | [2.3478, 3] |
| Discharge current (nominal, maximum) [$I_d$(A), $I_{d,max}$(A)] | [2.3478, 10] |
| Cycles Life at 100% DOD | 3000 |
| Cycles Life at 25% DOD | 100000 |

The following scenarios were investigated to see the effects of the SLEVB: 1) Discharging the brand new battery and SLEVB from 90% SOC, 2) Charging the brand new battery and SLEVB pack from 30% SOC.

*A. Peak Shaving Model*

The model designed compromises of a three-phase power supply connected to three-phase load. The battery is connected to the load through an inverter to supply the load. The block diagram of the model is shown in Fig. 3. In conventional power supply systems, the grid supplies the power for the load in peak and off-peak hours. In the proposed peak shaving model, during peak hours, the grid power is turned off and the load is supplied by the Battery Energy Storage System (BESS). The BESS supplies the load through the inverter. During the off-peak hours, the grid supply is turned back on and the BESS is charged during this period.

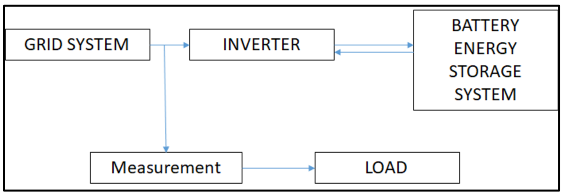


Fig. 3. Peak Shaving Model.

Each of the block is designed in detail using Simulink, however, due to space limitations, the detailed Simulink bocks are not shown in this work. The process of the design is explained subsequently.

The grid system uses a 3-phase voltage source to simulate the voltage generated by the electrical grid. The voltage source is connected to a circuit breaker to simulate the switching times between grid and battery power. The voltage source supplies a phase-to-phase voltage of 25 $kV_{rms}$ at a frequency of 60 Hz.

The inverter system is a 3-phase voltage source inverter design [26]. The load for the design is assumed to be the data centre load [27, 28]. A breakdown of the load is shown in Fig. 4, where a mid-tier data centre of 1.1 MW is assumed.

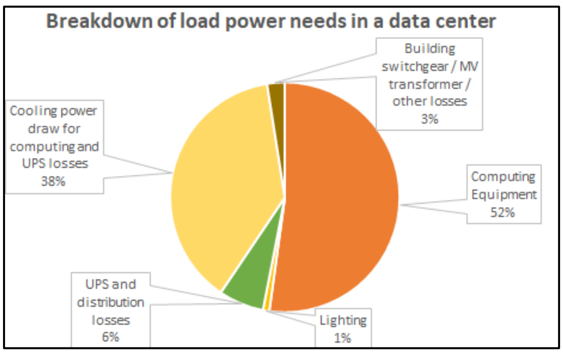


Fig. 4. Load components for a typical 465 m² data centre [28].

The battery pack used in the model was assumed to be Nissan LEAF Lithium-ion battery [29]. The specifications of the Nissan Leaf battery pack are summarised in Table II.

Table II. Nissan leaf battery pack specifications [29].

| | |
|---|---|
| No of modules | 24 |
| No of cells | 192 (2 in parallel and 96 in series) |
| Rated Voltage | 350 V |
| Capacity | 40 kWh or 114 Ah |
| External Dimensions | 1547 × 1188 × 264 mm |
| Weight | 303 kg |
| Weight energy density | 132 Wh/kg |

The design assumes that the battery used in the model have a capacity to supply the 465 $m^2$ data centre. The battery pack was assumed to have a voltage of 350 V with 3000 Ah capacity. In order to meet the requirements for the data centre, 27 Nissan leaf pack batteries are used together to have a combined capacity of 3000 Ah or 1050 kWh. The cost of brand new battery is assumed to be RM 522.9 / kWh with a lifespan of 10 years [30] while the SLEVB cost was assumed to be RM 182.72 / kWh [31].

*B. Battery Saving Computation*

The energy usage of the battery pack during charging and discharging is calculated using [32]

$$Energy\ (kWh) = Power\ consumed\ (kW) \text{x}\ Time\ (hour) \quad (1)$$

The total cost incurred due to the electricity rates can be calculated using

$$Total\ cost\ (RM) = Energy\ consumed\ (kWh) \text{x}\ Tariff\ rate\ \left(\frac{RM}{kWh}\right) \quad (2)$$

The tariff rates assumed in the calculations were taken from the Malaysian TNB Tariff book [32], where Tariff E2 for Medium Voltage Peak / Off Peak Industrial Tariff is assumed. For each kilowatt of maximum demand per month during the peak period, RM24.40 per kW is charged. All kWh during peak period is charged 24.40 sen/kWh while off peak is charged 23.40 sen/kWh.

## III. Results and Discussion

Table III shows the summary of the results obtained for the brand new Li-Ion and SLEVB at 80% SoC and 40% SoC respectively.

Table III. Nissan leaf battery pack specifications [29].

| | Brand new Li-Ion | | SLEVB | |
|---|---|---|---|---|
| | 80% SoC | 40% SoC | 80% SoC | 40% SoC |
| Initial battery capacity | 80% | 40% | 75.58% | 26.75% |
| Battery charging voltage | 379.4 V | 376.1V | 379.25 V | 376.1V |
| Battery Discharging voltage | 377.48 V | 373.52 V | 377.20 V | 373.52 V |
| Battery charging Current | 124 A | 124 A | 120 A | 120A |
| Battery discharging Current | 580 – 600 A | 580-600A | 650A | 650A |
| Power needed to charge | 48 kW | 48.4kW | 48kW | 48kW |
| Output power during discharge | 210 kW | 210 kW | 200 kW | 200kW |

The calculated charging and discharging rates along with the estimated charging and discharging times are summarised in Table IV. These results showed that the brand new battery and the SLEVB performed comparatively.

The power required to charge, and the power output from the battery is used to estimate the savings per kilowatt hour for both brand new and SLEVB models. Table V shows the estimated daily savings for both the brand new and SLEVB.

From the cost breakdown in Table V, it can be observed that the SLEVB has a higher saving per month compared to the brand new life battery. The foremost reason for this finding is due to the cost of battery pack for the brand new battery.

From this study, it was found that SLEVB is capable of providing peak shaving in data centres. Even though, the 1st life battery had a higher charging rate and a slower discharging rate, it was found that the SLEVB is more feasible to be used in the data centre. The main reason behind this finding is due to the initial cost of the brand new battery which is approximately 300% more than the cost of the SLEVB.

Table IV. Comparison of charging and discharging parameters for brand new Li-ion and SLEVB.

| | Brand New Li-Ion | SLEVB |
|---|---|---|
| Charging rate | 3.57Ah/s | 3.06Ah/s |
| Discharging rate | 17.2 Ah/s | 18.75 Ah/s |
| Time to charge to 80% SoC | 5.8 h | 6.6 h |
| Time to discharge to 30% SoC | 2.22 h | 1.77 h |

Table V. Savings per year using brand new Li-ion battery and SLEVB.

| | Brand New Li-Ion | SLEVB |
|---|---|---|
| Energy required to charge from 30% SOC to 80% SOC | 560 kWh | 684.48 kWh |
| Energy output when discharge from 80% SOC to 30% SOC | 466.2 kWh | 354 kWh |
| Tariff charges during off peak hours to charge battery | RM 40.09 | RM 45.62 |
| Savings during peak hour* | RM 597.09 | RM 570.84 |
| Total savings per day | RM 557.00 | RM 525.22 |
| Projected savings for 10 years | RM 2,033,050 | RM 1,917,053 |
| Cost of battery pack (1050 kWh) | RM 549,045.00 | RM 383,721.46 |
| Total Savings per year | RM 148,400.50 | RM 153,333.15 |

*Assume that the battery bank supplies the average maximum demand of 20 kW per day during peak hour.

The SLEVB was found to be 20.27% less efficient when compared to the brand new battery. Due to this, the SLEVB as able to deliver the power to the data centre load for about 27 minutes less than the brand new battery. Despite the reduced efficiency, the important reason to consider SLEVB is the environmental benefits obtained from such battery use. As seen from the literature, the utilisation of SLEVB could reduce the energy demand and global warming potential (GWP) by 15-70 %. The feasibility showed that SLEVB can be used in energy arbitrage applications, such as peak shaving, which would eliminate the need for mining and manufacturing of brand new Li-Ion batteries.

## IV. CONCLUSION

From the base model it was found that the SLEVB was capable of supplying a constant load of 48 V with just a battery of 50 Ah with 24 V nominal capacity. The SLEVB showed a decrease in the total capacity as a result of aging. Despite having an EOL of 3000 cycles the battery was able to supply the same voltage as that of the brand new battery pack. The SLEVB battery was modelled to supply the loads of a mid-tier data centre. From the results obtained it was found that the SLEVB had a faster discharging rate and a slower charging rate compared to the brand new battery of same capacity. The study concluded that SLEVB could be used in second life application, namely used in energy arbitrage applications such as peak shaving. This second life application have a saving higher than the 1st life. Second life application had a savings of RM 153,333.15, while the 1st life battery had a saving of RM 148,400.50 which is RM 4,932.65 less than the SLEVB application.

Despite the savings from peak shaving is almost similar to the 1st life battery scenario, the 2nd life has substantial economic and environmental benefits over the 1st life. From the literature of this study, it is found that the repurposing of EV batteries lead to a reduction in the price of EVs and eventually offer a reasonable price for the 2nd life EV batteries, which would make it more feasible for the use of 2nd life batteries in the energy arbitrage and ancillary services in the future.

## REFERENCES

[1] Y. E. Durmus, H. Zhang, F. Baakes, G. Desmaizieres, H. Hayun, L. Yang, M. Kolek, V. Küpers, J. Janek, D. Mandler, S. Passerini and Y. Ein-Eli, "Side by Side Battery Technologies with Lithium-Ion Based Batteries," *Advanced Energy Materials*, vol. 10, no. 24, 2000089, 2020.

[2] A. Castillo and D. F. Gayme, "Grid-scale Energy Storage Applications in Renewable Energy Integration: A Survey," *Energy Conversion and Management*, vol. 87, pp. 885–894, 2014.

[3] Z. Zhang and P. Ramadass, "Lithium-Ion Battery Systems and Technology," in *Encyclopedia of Sustainability Science and Technology*, Springer, pp. 6122–6149, 2012.

[4] T. Bunsen, "Global EV Outlook 2019," *IEA, 2019*.

[5] M. H. S. M. Haram, J. W. Lee, G. Ramasamy, E. E. Ngu, S. P. Thiagarajah and Y. H. Lee, "Feasibility of Utilising Second Life EV Batteries: Applications, Lifespan, Economics, Environmental Impact, Assessment, and Challenges," *Alexandria Eng. J.*, vol. 60, no. 5, pp. 4517–4536, 2021.

[6] NC State University "Literature Review of Energy Storage Services," https://nccleantech.ncsu.edu/2018/12/04/energy-storage-study-final-report-released/ (accessed Oct 31 2021).

[7] Deloitte, "Battery Electric Vehicles Deloitte Insights." https://www2.deloitte.com/uk/en/insights/industry/automotive/battery-electric-vehicles.html (accessed Jan. 31, 2021).

[8] IDTechEx, "Second-life Electric Vehicle Batteries 2020-2030: IDTechEx." https://www.idtechex.com/en/research-report/second-life-electric-vehicle-batteries-2020-2030/681 (accessed Jan. 31, 2021).

[9] E. M. Laserna, I. Gandiaga, E. S. Zabala, J. Badeda, D.I. Stroe, M. Swierczynski and A. Goikoetxea, "Battery Second Life: Hype, Hope or Reality? A Critical Review of The State of The Art," *Renewable and Sustainable Energy Reviews*, vol. 93, pp. 701–718, 2018.

[10] "Data Center Energy Storage Market Size Report, 2020-2027," *Grandview Research*, https://www.grandviewresearch.com/industry-analysis/data-center-energy-storage-market (accessed Jan. 31, 2021).

[11] R. Rahmani, I. Moser and M. Seyedmahmoudian, "A Complete Model for Modular Simulation of Data Centre Power Load," 2018, [Online]. Available: http://arxiv.org/abs/1804.00703.

[12] M. Dayarathna, Y. Wen and R. Fan, "Data Center Energy Consumption Modeling: A Survey," *IEEE Comm. Surv. and Tut.*, vol. 18, no. 1, pp. 732–794, 2016.

[13] Okey Keke, "Data Center Redundancy: 2N vs N+1 | Digital Realty," 2020. https://www.digitalrealty.com/blog/2n-vs-n-1 (accessed Oct. 23, 2021).

[14] R. Reinhardt, B. A. García, L. C. Casals and S. G. Domingo. "Critical Evaluation of European Union Legislation on The Second Use of Degraded Traction Batteries," *13th Int. Conf. on the Europ. Ener. Market*, pp. 1-5, 2016.

[15] D. Strickland, L. Chittock, D. A. Stone, M. P. Foster and B. Price, "Estimation of Transportation Battery Second Life for Use in Electricity Grid Systems," *IEEE Transactions on Sustainable Energy*, vol. 5, no. 3, pp. 795-803, 2014.

[16] I. Mathews, B. Xu, W. He, V. Barreto, T. Buonassisi and I. M. Peters, "Technoeconomic Model of Second-life Batteries for Utility-scale Solar Considering Calendar and Cycle Aging," *Appl. Ener.*, vol. 269, 115127, 2020.

[17] W. Li, R. Long, H. Chen and J. Geng, "A Review of Factors Influencing Consumer Intentions to Adopt Battery Electric Vehicles," *Renew. and Sustain. Ener. Rev.*, vol. 78, pp. 318-328, 2017.

[18] G. Reid and J. Julve. "Second Life-batteries As Flexible Storage for Renewables Energies," *Bundesverband Erneuerbare Energie eV* (BEE), 2016.

[19] A. Beaudet, F. Larouche, K. Amouzegar, P. Bouchard and K. Zaghib, "Key Challenges and Opportunities for Recycling Electric Vehicle Battery Materials," *Sustainability*, vol. 12, no. 14, 5837, 2020.

[20] K. Richa, C. W. Babbitt, N. G. Nenadic and G. Gaustad, "Environmental Trade-offs Across Cascading Lithium-ion Battery Life Cycles," *The Int. J. Life Cycl. Assess.*, vol. 22, pp. 66-81, 2017.

[21] J. W. Lee, M. H. S. M. Haram, G. Ramasamy, S. P. Thiagarajah, E. E. Ngu and Y. H. Lee, "Technical Feasibility and Economics of Repurposed Electric Vehicles Batteries for Power Peak Shaving," *J. Ener. Storage*, vol. 40, 102752, 2021.

[22] Torque News ,"GM and ABB Demonstrate A Second Life for Used Chevy Volt Battery Packs," https://www.torquenews.com/1075/gm-and-abb-demonstrate-second-life-used-chevy-volt-battery-packs (accessed Oct. 26, 2021).

[23] "Bosch, BMW, Vattenfall Resurrect EV Batteries for 'Second Life' As Large-scale Energy ST", Energy Storage News, 2015. https://www.energy-storage.news/bosch-bmw-vattenfall-resurrect-ev-batteries-for-second-life-as-large-scale-energy-st/ (accessed Oct. 26, 2021).

[24] Fortuna C.,´ What's Possible for Used EV Batteries? Daimler Energy Storage Units Provide Second-life Power, *CleanTechnica*, Jun 2018. https://cleantechnica.com/2018/06/28/whats-possiblefor-used-ev-batteries-daimler-energy-storage-units-provide-second-life-power/ (accessed 29.5.2020).

[25] Himaxelectronics, "18650 Li-ion 12V 50Ah Battery Pack 12v 50ah Battery Pack." https://himaxelectronics.com/product-item/18650-li-ion-12v-50ah-battery-pack/ (accessed Oct. 10, 2021).

[26] "Simulink based Three Phase Voltage Source Inverter Simulation." https://microcontrollerslab.com/three-phase-voltage-source-inverter-simulink-model/ (accessed Oct. 17, 2021).

[27] T. L. Vasques, P. Moura, and A. de Almeida, "A Review on Energy Efficiency and Demand Response with Focus on Small and Medium Data Centers," *Ener. Effic.*, vol. 12, no. 5, pp. 1399–1428, 2019.

[28] G. Ghatikar, M. A. Piette, S. Fujita, A. McKane, J. H. Dudley

and A. Radspieler, "Demand Response and Open Automated Demand Response Opportunities for Data Centers," Lawrence Berkeley National Lab., 2010.

[29] Nissan Leaf, "Nissan Leaf Battery Specs.", 2018. https://pushevs.com/2018/01/29/2018-nissan-leaf-battery-real-specs/ (accessed Oct. 17, 2021).

[30] Renewable Energy World "Annual Survey Finds Battery Prices Dropped 13% in 2020," ." https://www.renewableenergyworld.com/storage/annual-survey-finds-battery-prices-dropped-13-in-2020/#gref (accessed Oct. 23, 2021).

[31] H. Rallo, G. Benveniste, I. Gestoso and B. Amante, "Economic Analysis of The Disassembling Activities to The Reuse of Electric Vehicles Li-ion Batteries," *Resour., Conser. and Recycl.*, vol. 159, 104785, 2020.

[32] "Tariff Book," https://www.tnb.com.my/residential/pricing-tariffs (accessed Oct 18, 2021).