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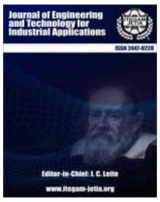

RESEARCH ARTICLE OPEN ACCESS

A COMPARATIVE ANALYSIS OF FAST CHARGING PERFORMANCE AND BATTERY LIFE AGAINST CHARGING CURRENT VARIATIONS

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ABSTRACT

The increasing demand for fast-charging batteries presents challenges related to charging speed and battery lifespan. This study compares the performance of lithium-ion and solid-state batteries under varying charging currents. At a charging current of 50 A, lithium-ion batteries require approximately 140 seconds to charge fully, while solid-state batteries achieve the same in about 130 seconds. However, at higher currents (300 A), lithium-ion batteries significantly reduce charging time to 20 seconds, while solid-state batteries charge in 18 seconds. Despite this, high current charging accelerates battery degradation. Lithium-ion batteries, for example, have a lifespan of about 1,200 cycles at 50 A, which decreases drastically to near 0 cycles at 300 A. In contrast, solid-state batteries maintain a higher cycle life, reducing from 1,000 cycles at 50 A to around 100 cycles at 300 A. Solid-state batteries exhibit superior performance, particularly in high-current conditions, with 600 cycles at 150 A, compared to only 200 cycles for lithium-ion. The results highlight a trade-off between charging speed and battery life, with faster charging achieved at the expense of battery longevity, especially for lithium-ion. Solid-state technology provides a more balanced solution, offering faster charging times and better longevity, making it suitable for high-power applications.

I. INTRODUCTION

Vehicle-to-Grid (V2G) technology enables a bidirectional flow of energy between electric vehicles (EVs) and the grid, offering a range of benefits and challenges [1]. V2G can provide additional services such as voltage and frequency control, reactive power support, and load balancing [2]. This technology facilitates the integration of renewable energy sources and supports smart grid applications [3]. However, uncoordinated EV charging can negatively impact the power system, requiring optimized coordination [3]. V2G implementations face challenges including battery degradation, infrastructure modifications, and high investment costs [4], [5]. Despite these barriers, V2G offers potential benefits for EV owners and network operators, such as improved network efficiency, reliability, and demand-side management [5]. As EV adoption increases, V2G technology is expected to play a crucial role in future smart grid systems [2].

The development of faster, more rechargeable and more durable batteries is a priority in driving the adoption of electric vehicles (EVs). Lithium-ion batteries, which have become the standard for EVs, face some limitations, especially on fast charging efficiency and cycle life. Fast charging on Li-ion often leads to "lithium plating" and overheating which shortens the life of the battery and reduces its capacity over time. However, solutions such as active thermal modifications have shown significant improvements in charging times to just 15 minutes, while keeping cycle life adequate (±500 cycles) as per the U.S. Department of Energy (DOE) target [6]. In contrast, solid-state battery technology offers advantages such as higher safety, greater energy density, and much faster charging potential with longer cycle life. Research at Harvard, for example, has shown that solid-state designs with lithium-metal anodes can achieve up to 10,000 fill cycles with a fill time of just a few minutes. This technology also addresses the growth of dendrites that are usually a problem in other solid-state batteries, thus providing better material stability [6].

A direct comparison between these two technologies shows that solid-state can be a superior solution in terms of charging speed and endurance, but it still faces challenges in terms of production scale and cost. Lithium-ion remains superior in widespread adoption due to its lower cost and mature technology, but innovations in fast-charging modifications continue to make it competitive in the Market [6-8].

II. THEORETICAL REFERENCE

Vehicle-to-Grid (V2G) is an innovative technology that allows Electric Vehicles (EVs) to not only receive power from the grid through fast charging but also return power to the grid when needed. Thus, electric vehicles function as a two-way power source [9]. When electricity demand is low and supply is excessive (e.g., at night), electric vehicles can be charged using fast charging to shorten charging times. In times of high electricity demand or a power shortage on the grid (for example, during daylight hours or peak hours), the energy stored in the electric vehicle battery can be returned to the grid. This helps stabilize the power grid. V2G technology relies on a two-way communication system between EVs, charging stations, and power grids. This allows for automatic and real-time management of power flow.

Fast charging allows charging in a short time, making the vehicle ready for use or providing power to the grid in a faster time. With shorter charging times, vehicles can more quickly contribute to grid stabilization. V2G technology helps maximize investment in fast charging infrastructure as charging and power return can be regulated more efficiently. The use of bidirectional batteries via V2G can accelerate battery degradation, especially if fast charging is used repeatedly. Therefore, it is necessary to pay attention to the impact of battery degradation.

Discussions related to fast charging and lifespan performance of lithium-ion (Li-ion) and solid-state (SSB) batteries include several important aspects of battery design, materials, and limitations.

1. Solid-State Battery Advantages:

Solid electrolytes (often ceramic-based) in SSBs can physically block lithium dendrites, which are a major cause of short circuits in liquid-electrolyte batteries. This allows for potentially safer and faster charging systems compared to traditional Li-ion batteries [10]. he non-flammable nature of solid electrolytes and their high ionic conductivity offer promising advantages for electric vehicles and other applications requiring fast charging [11] [12].

2. Challenges in Fast Charging:

Fast charging introduces mechanical stress and nanoscale defects in solid electrolytes. These stresses can create microcracks and fissures, allowing lithium ions to intrude and potentially short-circuit the battery. Such defects arise from high current densities and uneven pressure across the electrolyte surface during charging [11], [12]. In Li-ion batteries, higher charging currents increase the risk of side reactions like lithium plating, leading to reduced cycle life and thermal runaway risks [10], [11].

3. Battery Lifetime Considerations:

The lifetime of Li-ion batteries decreases significantly with higher charging currents due to the degradation of the liquid electrolyte and electrode materials. In contrast, SSBs are designed to mitigate such issues but face challenges related to the stability of solid electrolyte interfaces [10], [7]. The improvement of interfacial compatibility between electrodes and solid electrolytes is crucial for extending the cycle life of SSBs during high-rate charging [7], [12].

4. **Design and Material Innovations**:

Researchers are investigating strategies to reinforce solid electrolytes by coating their surfaces or using additives to heal cracks during operation [11], [12]. Advances in materials science, such as the development of highly conductive solid-state electrolytes and optimized electrode designs, are key to overcoming the performance trade-offs seen in fast-charging batteries [11], [12].

These theories and insights help to explain the performance trends seen in the graph you provided, where charging times decrease with higher currents, but the lifetime of batteries, especially Li-ion ones, diminishes significantly. Innovations in SSBs aim to address these trade-offs by enabling both faster charging and longer lifespans [11], [12]. This paper presents a novel design for a photovoltaic (PV) powered electric vehicle (EV) charging system. The core of the system is a modified single ended primary inductance converter, chosen for its high efficiency, reduced switch voltage stress, and ample operating range for maximum power point tracking (MPPT). This study details the redesigned SEPIC converter architecture, including with and without the MPPT algorithm. Additionally, it presents an optimized parameter selection, design methodology, and simulation technique for analysing the converter's performance in EV charging applications. The simulation results demonstrate that under identical simulated conditions (10 seconds), the battery SoC increases from 50% to 50.034% without MPPT and to 50.042% with MPPT, highlighting the effectiveness of the MPPT algorithms in maximizing harvested solar energy [13].

Many battery applications target fast charging to achieve an 80 % rise in state of charge (SOC) in < 15 min. However, in the case of all-solid-state batteries (SSBs), they typically take several hours to reach 80 % SOC while retaining a high specific energy of 400 Wh [14]. In another study, multi-type fast charging stations are expanding across Europe as electric vehicle (EV) adoption rises, but diverse weather conditions pose challenges. This study evaluates fast charging (up to 50 kW) at ambient (25°C) and extreme temperatures (−25°C, −15°C, +40°C) using seven chargers and two EVs (CCS, CHAdeMO). Power conversion efficiency, calculated per SAE J2894/1, shows significant performance variations: efficiency drops at extreme temperatures due to reduced power demand. Results reveal efficiencies ranging from 39% at −25°C to 93% at 25°C, highlighting the impact of temperature on fast charging performance [15]. Power systems are run by combining different energy producers while the demand serves as the system’s energy user and covers all of the non-flexible and flexible loads, including electric vehicles (EVs). This study investigated the trip pattern impact of EVs, utilizing the Orca Algorithm (OA), in optimizing power production, applied to the IEEE-62 bus system as a model [16]. Orca Algorithm is used in this work to solve the UC problem with the IEEE-62 bus system as the model, where loads are linked with flexible loads where the flexible load in this study is determined by the driving habits of an electric vehicle (EV) [17]. This paper reviewed the linkage between the latest research contributions, issues associated with TSCC and SSC techniques, and the performance evaluation of the techniques, and subsequently identified the research gaps and proposed SSC control with SOC consideration for further research studies. TSCC methods deploy current or voltage control for controlling EVs’ SOC battery charging through proportional-integral (PI), proportional-resonant (PR), deadbeat or proportional-integral-derivative (PID) controllers, but these are relegated by high current harmonics, frequency fluctuation and switching losses due to transient switching [18]. During 24 hour operations, the model that is often used is Dynamic Economic Operation (DEO) which takes into account changes in load demand over a 24 hour seven day period. This study uses the IEEE-62 bus system as a model, which is optimized using the Orca Algorithm. The load flexibility pattern is based on the effect of charging integration for Electric Vehicles (EV) [19].

III. METHODOLOGY

In this article, the method used in this study is qualitative and models based on existing data, modeling using Python software with modeling parameters to measure charging time and evaluating battery life by taking into account the variation of charging current. Here are the steps taken:

1. Charging Time Testing:

   Lithium-ion and solid-state batteries are recharged using varying levels of charging current (from 50 A to 300 A). The time it takes to reach full capacity (or to a certain extent, such as 80% State of Charge) is measured for each technology.

2. Cycle Life Evaluation:

   The battery charge-discharge cycle is carried out until the capacity degradation reaches a certain limit (e.g., 80% of the initial capacity). Cycle life data is collected for each charge current level, noting the effect of large currents on battery performance degradation.

3. Comparative Testing:

   Measurement results are compared for both types of batteries, focusing on: The relationship between the charging current and charging time.

The modeling in this study was carried out by using python software on Lithium-ion and Solid-state battery types to see the extent of fast charging performance and battery life to the variation of charging current. To examine the effect of electric vehicle batteries during charging with V2G, where voltage and current rise, we can use a mathematical model. This model considers the relationship between voltage, current, charging time, and its effect on battery life.

1. Relationship of Voltage, Current, and Power

The basic equation is Ohm's law and electrical power:

$$P = V.\, I \tag{1}$$

Where:
P: Charging power (W)
V: Charging voltage (V)
I: Charging current (A)
With V = 20 kV during fast charging, the current (I) also increases according to the power requirement (P).

2. Charging Time

The t_c charging time can be determined by dividing the stored energy by the charging power:

$$t_c = \frac{E}{P} = \frac{Q.V_{batt}}{V.I} \tag{2}$$

Where:
E: Total energy stored in the battery (Joules)
Q: Battery capacity (Coulomb or Ah)
V_{batt}: Nominal voltage of the battery (V)

High voltage (V) and high current (I) will lower tc, so charging takes place faster.

3. Battery Lifetime

The lifetime of the battery is affected by the high charging current and charging cycle frequency. The degradation rate can be calculated by:

$$D = k.I^{\propto}.e^{\frac{T}{T_0}} \tag{3}$$

Where:
D: Battery degradation per cycle
k: Battery material constant
I: Charging current (A)
α: Exponential current sensitivity to degradation
T: Battery temperature (K)
T_o : Reference temperature (K)

The total lifetime of a battery is the opposite of accumulated degradation:

$$L\frac{1}{\sum D} \tag{4}$$

From the available data, the modeling is then continued by combining a high voltage paremeter (V=20 kV) causing a high current I, so that tc decreases. However, a high I increases D, accelerates degradation, and decreases L. Balance between tc and L is key to fast charging with V2G. Optimization is carried out by choosing the ideal combination of V, I, and T to maintain battery life.

IV. RESULTS AND DISCUSSIONS

IV. 1 FAST CHARGING MODEL SIMULATION

In Fast Charging conditions, it is necessary to know the charging time of the battery with various charging currents to achieve a full charge in a shorter duration. Charging Current is a variable that is tested to see the effect of charging current on charging time and battery life. Battery LifeRepresentation of the number of charge-discharge cycles before the battery capacity drops to an unacceptable level. The fast charging model for electric vehicles often refers to a charging strategy with two main stages:

1. Constant Current Charging (CC) Phase: At this stage, the charging current is kept at the maximum value (10 A in this case) until the battery voltage is close to the maximum limit.
2. Constant Voltage Charging (CV) Stage: After the battery voltage reaches its maximum value, the charging current gradually decreases to prevent battery damage, until the battery is fully charged.

Previously, it was necessary to conduct simulations to determine fast charging conditions using a constant current (CC) and constant voltage (CV) approach, taking into account time (CT) to regulate the charging speed. At constant current (CC), the charging process occurs at a constant current until a certain voltage is reached. Where the constant voltage (CV) after reaching the maximum voltage, with charging at a constant voltage and the current decreasing gradually, the charging time required is less without damaging the battery. The simulation results can be seen in the graph figure 1.

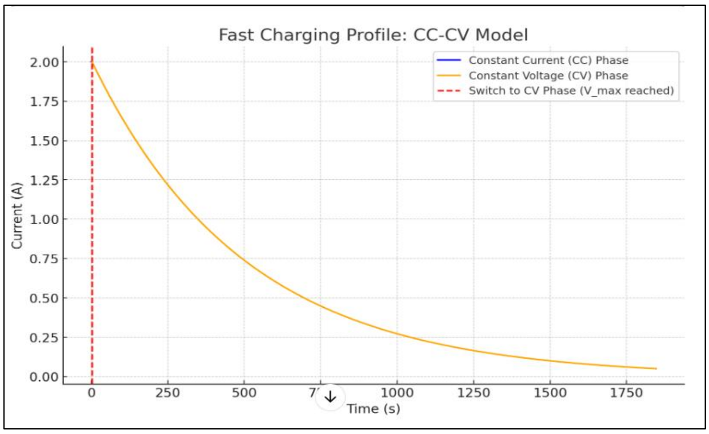

Figure 1: Fast charging profile.
Source: Authors, (2025)

Based on the simulation results in Figure 1, the graph shows the CC-CV charging profile. The blue line shows the constant current (CC) phase, where the current remains stable until the battery reaches Vmax. The orange curve shows the constant voltage (CV) phase, where the current gradually decreases as the battery is nearly fully charged.

The dashed red line marks the transition point from CC to CV phase. This model helps visualize the effect of fast charging on current flow over time. The calculated charging time for this fast charging model is obtained as Constant Current (CC) Phase Time: 2.1 seconds, Constant Voltage (CV) Phase Time: 1844.44 seconds, Total Charging Time: 1846.54 seconds (about 30.78 minutes).

To optimize charging in the context of fast charging vs. normal charging, the model considers two main goals that often conflict:

1.Minimization of Charging Time (tc). Reduce charging time to improve user comfort.

2.Max. Battery Lifetime (L). Reduce battery degradation to extend its lifespan.

To see the comparison of charging electric vehicles in fast charging conditions with normal charging, a simulation was carried out where the voltage value during fast charging V = 20000 (20 kV in V), Q value = 100 Battery capacity in Ah, and V_batt = 400 Nominal battery voltage (V). Simulations were carried out to see how much current was allowed and how long it took to charge. The simulation results with phyton are obtained in fast and normal charging conditions, graphically shown in Figure 2.

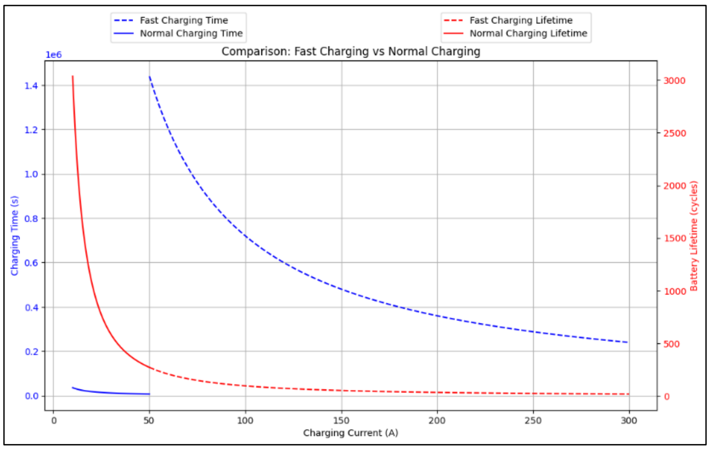

Figure 2: Fast and Normal charging.
Source: Authors, (2025).

Based on the graph in Figure 2, a comparison of charging time and battery life for two different charging methods is obtained: fast charging and normal charging. Charging Time vs. Charging Current. The blue curve represents the charging time for fast charging, which decreases significantly as the charging current increases. For example, at low charging currents (near 0 A), the charging time is very long (close to 1 million seconds), while at higher currents (around 300 A), the time drastically drops to nearly 0.2 seconds. In contrast, the normal charging time (dashed blue curve) decreases more gradually, indicating that normal charging takes significantly longer, even at higher charging currents. This shows that normal charging is less sensitive to changes in charging current compared to fast charging.

Battery Lifetime vs. Charging Current. The red curve represents the battery lifetime for fast charging. As the charging current increases, the battery lifetime decreases. At low charging currents (50 A), the battery has a higher lifetime (around 2,500 cycles), but as the current increases (up to 300 A), the lifetime sharply drops to around 500 cycles. This is indicative of how faster charging can lead to faster battery degradation due to higher heat generation and stress on the battery. The normal charging lifetime (dashed red curve) is more stable, showing a much slower reduction in battery lifetime. At higher currents (e.g., 300 A), the lifetime only slightly decreases, reflecting the fact that normal charging places less strain on the battery. This analysis highlights the trade-off between fast charging and battery longevity, suggesting that high current charging (fast charging) can significantly reduce battery lifespan, while normal charging offers a better balance of performance and longevity.

After getting a comparison of fast and normal conditions, it is next to see how the optimal current affects the charging and degradation time. The simulation is carried out by expanding to a more optimal multiobjective optimization. Conditioned if it charges faster without damaging the battery. The simulation results are obtained graphically shown in figure 3.

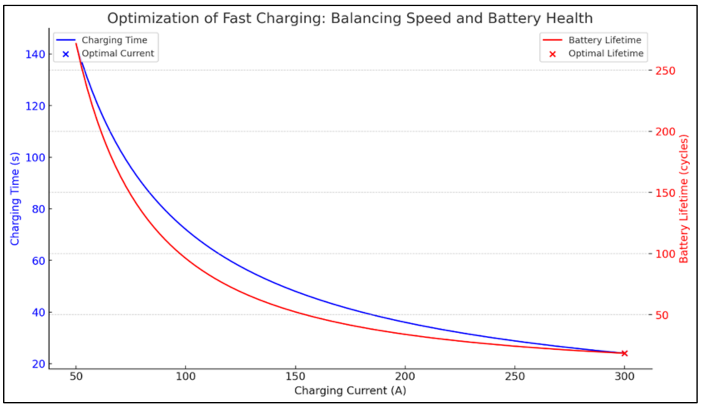

Figure 3: Effect of optimization on battery degradation.
Source: Authors, (2025)

From the simulation results obtained in figure 3. The graph displays: The graph displays Charging Time (blue curve): Decreases with increasing current. Battery Lifetime (red curve): Decreases sharply as current increases. The optimal solution maximizes charging speed while balancing battery health. The trade-off suggests that extreme fast charging significantly reduces battery lifetime, requiring careful design of charging profiles. Charging Time (blue curve): Decreases with increasing current. Battery Lifetime (red curve): Decreases sharply as current increases. The optimization results indicate the following:

- **Optimal Current (I)**: 300.0A

- **Charging Time (tc)**: 24.0seconds
- **Battery Lifetime (L)**: 18.49cycles

IV. 2 THE EFFECT OF FAST CHARGING ON BATTERIES

After obtaining the optimal values on the current, time and life of the battery, it is then necessary to compare lithium-ion batteries with solid-state batteries in the context of fast charging by considering several important aspects, such as:

1. Charging characteristics. Lithium-ion batteries have a lower charge current limit than solid-state batteries. Solid-state batteries are more thermally stable, so they can handle higher charging currents.
2. Battery degradation. Lithium-ion is more susceptible to degradation due to the growth of the SEI (Solid Electrolyte Interphase) layer. Solid-state has lower degradation because the electrolyte is dense and more stable.
3. Lifetime.Solid-state typically has a longer lifetime in fast-charging conditions.

Fast charging technology allows batteries, particularly in electric vehicles, to charge at much higher rates, reducing overall charging time significantly. However, this convenience comes with notable trade-offs related to battery health, performance, and lifespan. Fast charging subjects batteries to higher currents, which results in: Increased heat generation: High current during charging causes significant heat buildup. Elevated temperatures can accelerate chemical reactions within the battery, leading to thermal stress and faster material degradation

The modeling was carried out to see the implications on the fast charging conditions of the two types of batteries, the simulation results were obtained as shown in Figure 4.

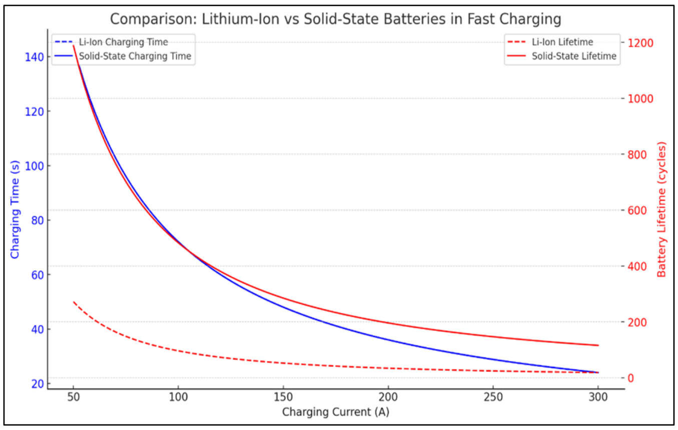

Figure 4: Comparison of fast charging performance
Source: Authors, (2025).

The results obtained are based on Figure 4. The graph compares the performance of lithium-ion and solid-state batteries during fast charging. Charging Time (blue), Lithium-ion and solid-state batteries have similar charging times, as both depend mainly on the charging current. Battery Life (red), Lithium-ion batteries experience a sharper decrease in life as the charging current increases. Solid-state batteries show much better life retention at higher charging currents due to their stable solid electrolyte.

Judging from the charging time, Solid-State is more efficient (faster) compared to Li-Ion at higher currents, indicated by a solid red line that is lower than the solid blue line. At current I=300A, the charging time is close to the minimum value (about 20-30 seconds). Meanwhile, in terms of battery life: Lithium-Ion experiences faster degradation of life as the charging current increases, as seen from the dotted blue line that is close to 0 at I→300A. Solid-State is more durable at high currents, with battery life still significantly higher than Li-Ion.

Mathematically, it can be said that the charging time (T) is inversely proportional to the charging current (I). Battery life (L) shows a significant decrease as the current increases, with Lithium-Ion decreasing more drastically than Solid-State. Solid-State batteries excel in both charging time efficiency and battery life endurance at high currents.

The results of the simulation are reinforced by the regression results showing that the mathematical model for the charging time (T) as a function of the charging current (I) is:

$$T = \frac{689.07}{I} + 75.27 \tag{5}$$

Interpretation:

- **Parameter a=689.07**: Indicates the main contribution of the current inverse component (1/I) to the charging time.
- **Parameter b=75.27**: Indicates a relatively constant minimum charging time component.

Large voltages in electric vehicle charging systems, in this case V2G systems, can affect EV battery life through several mechanisms:

1. Battery Degradation Due to High Voltage: Charging or discharging at high voltages can accelerate the chemical degradation of the battery, leading to a faster decrease in capacity and reduced lifespan. This happens because high voltages can increase the risk of lithium plating formation on the anode of the lithium-ion battery.
2. Recharge Cycle Effect: Frequent use of V2G requires the battery to go through many charge and discharge cycles, which will accelerate the chemical degradation of the battery.
3. Operating Temperature: Higher voltages generate greater current, and this can increase the temperature of the battery, accelerating cell wear and tear if the cooling system is not optimal. By optimizing the voltage and current in the V2G system, we can reduce the rate of battery degradation and extend the battery life of electric vehicles.

V. CONCLUSION

Based on the research that has been done on lithium-ion batteries and solid-state types, it can be concluded. In both types of batteries, the charging time is significantly reduced with increasing charging current. At a current of 50 A, the charging time for lithium-ion batteries reaches about 140 seconds, while solid-state requires a slightly shorter time, about 130 seconds. At a current of 300 A, the charging time for lithium-ion drops to about 20 seconds, while solid-state remains marginally faster at 18 seconds.

Battery life degradation at high currents, Battery life, measured in cycles, shows faster degradation at high charging currents. Lithium-ion batteries, for example, have a life of about 1,200 cycles at low currents (50 A), but drop dramatically to almost 0 cycles at 300 A. In contrast, solid-state batteries show better performance, starting at 1,000 cycles at 50 A and only dropping to about 100 cycles at 300

Battery resistance to fast charging, solid-state has the advantage of maintaining battery life at high currents compared to lithium-ion. At 150 A current, lithium-ion has a life of only about 200 cycles, while solid-state still reaches about 600 cycles, showing much better resistance to degradation. Charging time and battery life show a trade-off between charging time and battery life.

Increasing the charging current does reduce the charging time to about 10 times faster (from 140 seconds to 20 seconds for lithium-ion), but at the expense of battery life, especially for lithium-ion which almost loses its cycles at high currents. Solid-state provides a more balanced solution by maintaining a longer battery life at high currents.

Lithium-ion: Offers good charging performance but degrades faster under high current. Solid-state: Supports faster charging with less degradation, making it more suitable for high-power applications.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Samsurizal and Arif Nur Afandi.
Investigation: Samsurizal.
Discussion of results: Samsurizal, Arif Nur Afandi and Mohamad Rodhi Faiz
Methodology: Samsurizal, Arif Nur Afandi.
Writing – Original Draft: Samsurizal, and Arif Nur Afandi.
Writing – Review and Editing: Samsurizal, Arif Nur Afandi. Mohamad Rodhi Faiz
Supervision: Arif Nur Afandi and Mohamad Rodhi Faiz
Approval of the final text: Samsurizal and Arif Nur Afandi.

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