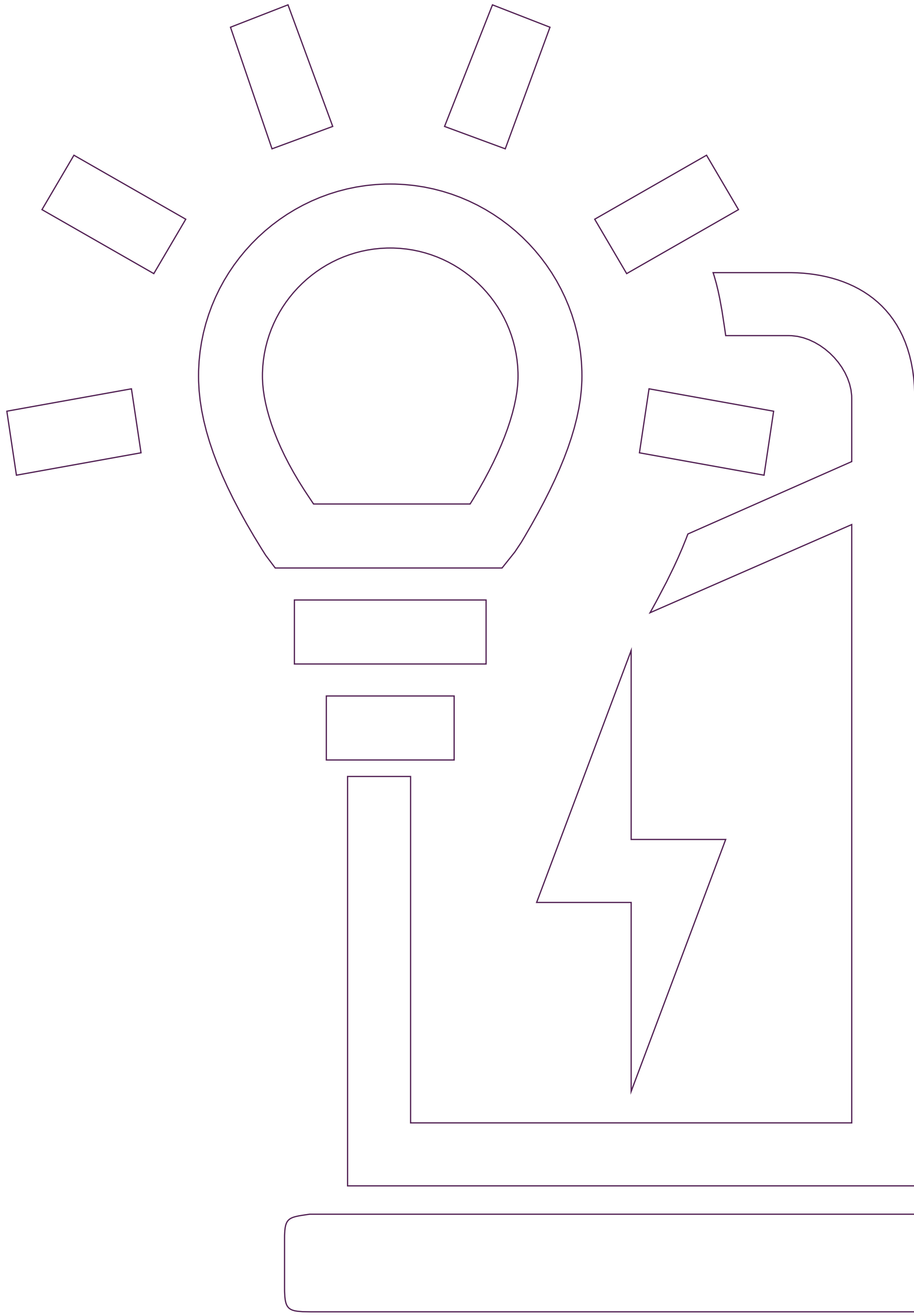
REPORT

OPPORTUNITY CHARGING FOR E-BUSES

INSIGHTS AND TIPS FOR OPTIMIZING CHARGING BEHAVIOR



VIRICITI

EXECUTIVE SUMMARY

ViriCiti connects to more than **1200 charger sockets** (plugin & pantograph) across the world and has registered almost **3 million charging transactions** from over **1000 vehicles** since 2018.

With such rich data on charging transactions and the use of chargers, we saw the chance to provide new industry insights into the use of opportunity charging.

To that end, **we analyzed 40,000 charging sessions from ~190 charging stations**.

As currently there is no benchmark definition of opportunity charging, we looked at existing literature and defined opportunity charging for our research as charging sessions happening during regular service hours (5AM-11PM), with a duration of maximum 60 minutes[8], done through on-route chargers with a minimum power of 100KW. More details are available in the "Definitions and Methods" section.

The results indicate that on average, the energy charged per opportunity charging session is **64.7 kWh**, while the average duration of an opportunity charging session is close to **26 minutes**, with **54%** of analyzed sessions **under 10 minutes**. Furthermore, we have noticed that most sessions occur during the weekdays when passenger traffic is higher, and during rush hour intervals.

Finally, operators start charging their buses on-route at an already high state-of-charge (SoC*) level, averaging at around **64%**, which correlates to a high ending SoC value (averaging **88.5%**). This leads to the conclusion that operators underutilize their high power chargers, because at high SoC levels the charging power drops dramatically.

This report is the result of meticulous research that was fine-tuned over several months.

* in this report by SoC we mean technical SoC.

RESULTS

SUMMARY STATISTICS

WE ANALYZED

Chargers

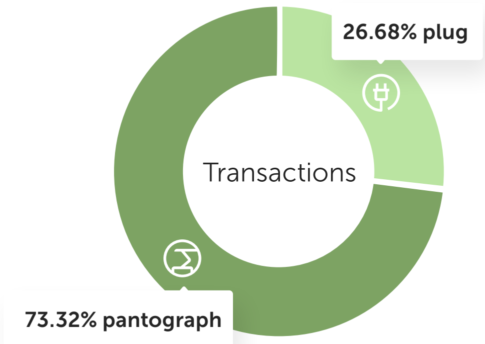
187

Charging sessions

40k

MWh

2821



CHARGING SESSION TIMES

Average charging session time

25.9 minutes

Median charging session time

21 minutes

54% of charging sessions last less than

10 minutes

START AND END SOC

Average SoC value at the beginning of the session

63.89%

Average SoC value at the end of the session

88.51%

OPPORTUNITY CHARGING PER DAY / HOUR

We observe a drop in the number of opportunity charging sessions during the weekends (Figure 1). This phenomenon could be potentially explained due to the reduction in the number of buses on the road during these days.

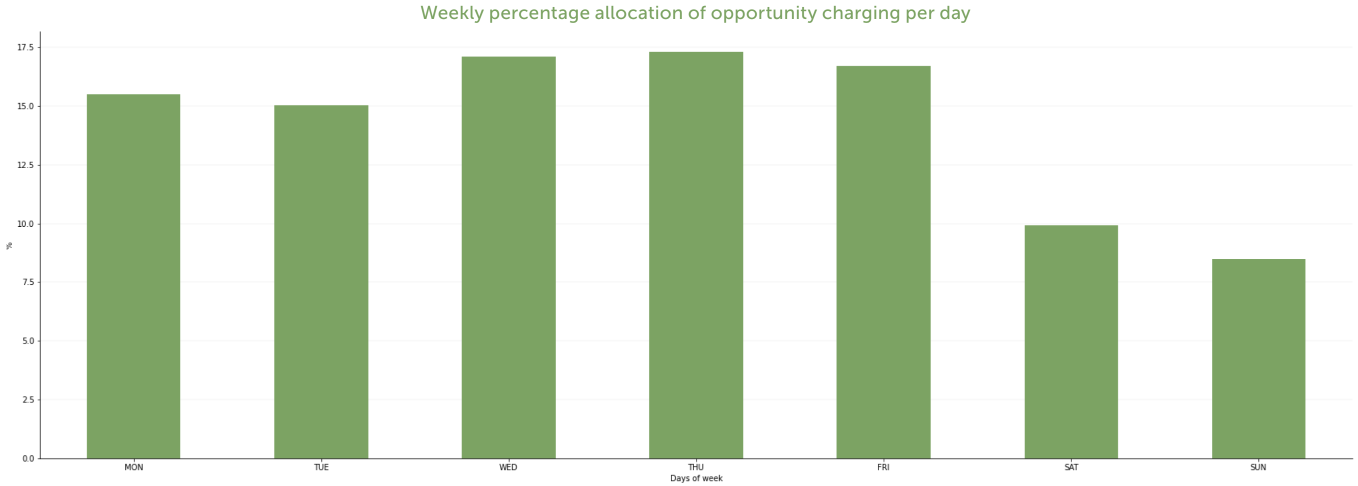


Figure 1

We also observe an increase in the number of opportunity charging sessions between 9AM-10AM (figure 2). The data shows that between 7AM-10AM, as well as 4PM-7PM, the average charging session lasts 15.54 minutes compared to 28.56 minutes outside these intervals.

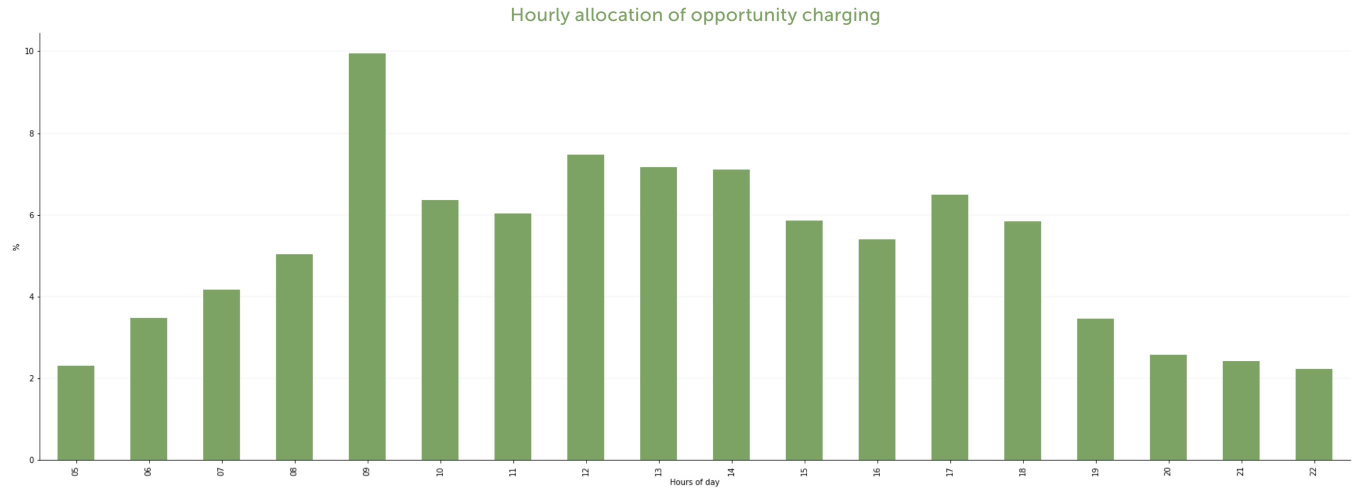


Figure 2

START AND END STATE-OF-CHARGE (SOC)

Almost **24% of the sessions** start at an SoC level of **80% or more**.

In other words, around a quarter of all charging sessions observed start when the battery is over 80% charged. The average SoC of the analyzed sessions is also high, namely 63.89%.

The consequences are further discussed in the report.

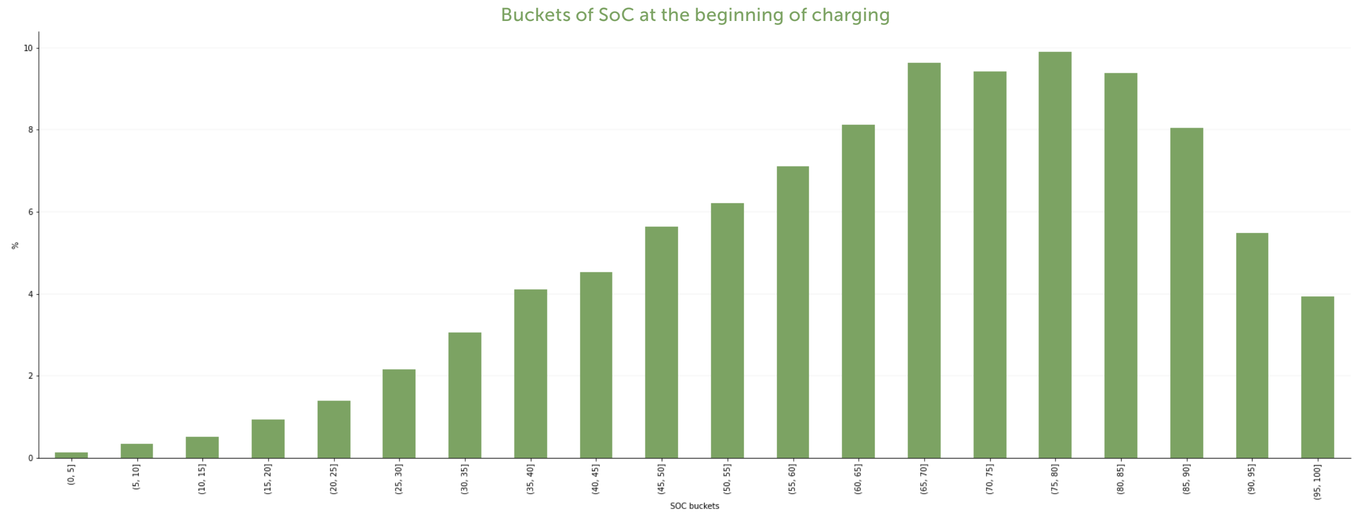


Figure 3: Percentage of appearances at the beginning of session

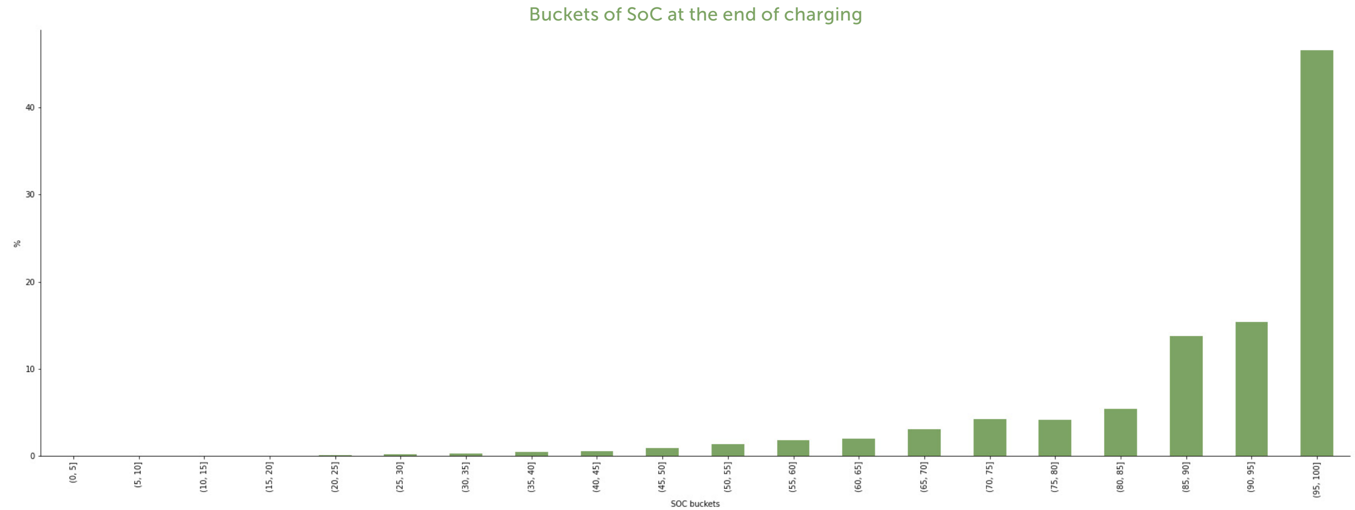


Figure 4: Percentage of appearances at the end of the session

WHAT DOES IT ALL MEAN?

One of the most interesting findings of this report is that operators start opportunity charging sessions when buses have high SoC values. As a result, they are only using the top half of the battery. Our findings show that these situations occur frequently, with over 24% of the charging transactions analyzed starting at SoC of 80% or more.

This is problematic because batteries usually don't like to be stalled and operated close to 100% (or close to 0%) SoC. As a tendency, it's preferable to operate them at 50% SoC on average, which can be a problem for opportunity charging[1] [3].

The upside of this behavior is that it helps eliminate range anxiety as buses are planned very conservatively.

The downside, however, is that buses do not utilize the high charging speeds usually offered by the opportunity chargers.

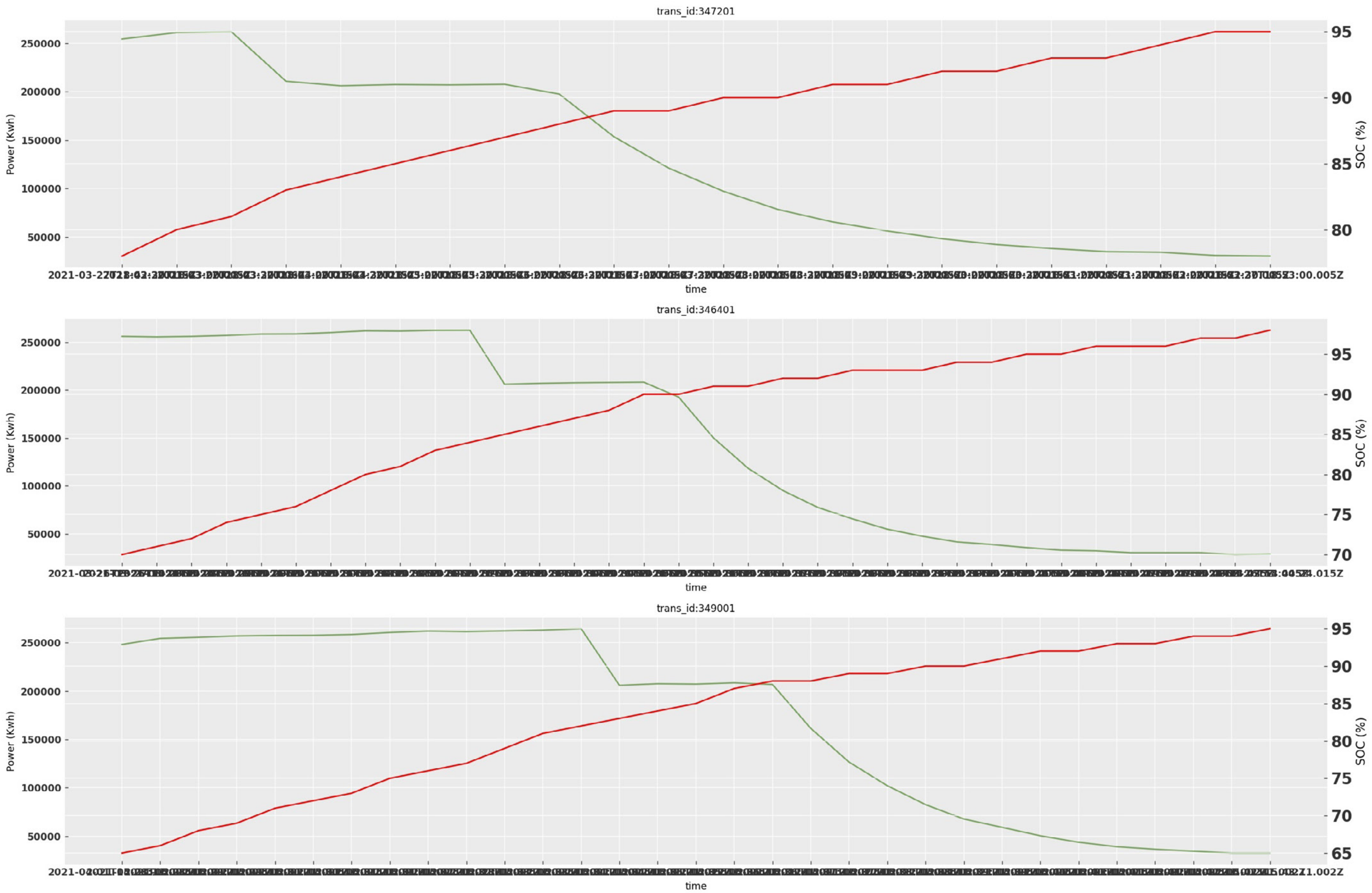


Figure 5

This happens because the charging speed of a charger does not remain constant for the whole duration of the charging session. Rather, it slows down when high SoC values are reached. The threshold when this phenomenon appears can vary per charger and bus type, but the rule of thumb is that it starts appearing at an SoC of around 80% [1] [2].

One of the reasons behind this is that the BMS (Battery Management System) reduces the charging power to avoid overheating the battery cells. As a result, buses which start charging at high SoC cannot charge at full power throughout the short charging sessions.

To illustrate this dramatic drop in the power when a higher SoC, have a look at the transactions shown below in Figure 5. These graphs represent chargers with a maximum power of 100 KW and 350 KW.

The exact threshold for the drop in the power cannot be strictly determined as it depends on a variety of reasons (such as charger type and type of connected vehicle), but in most cases, we observe a drop in charger power for SoC values of 80% or higher.

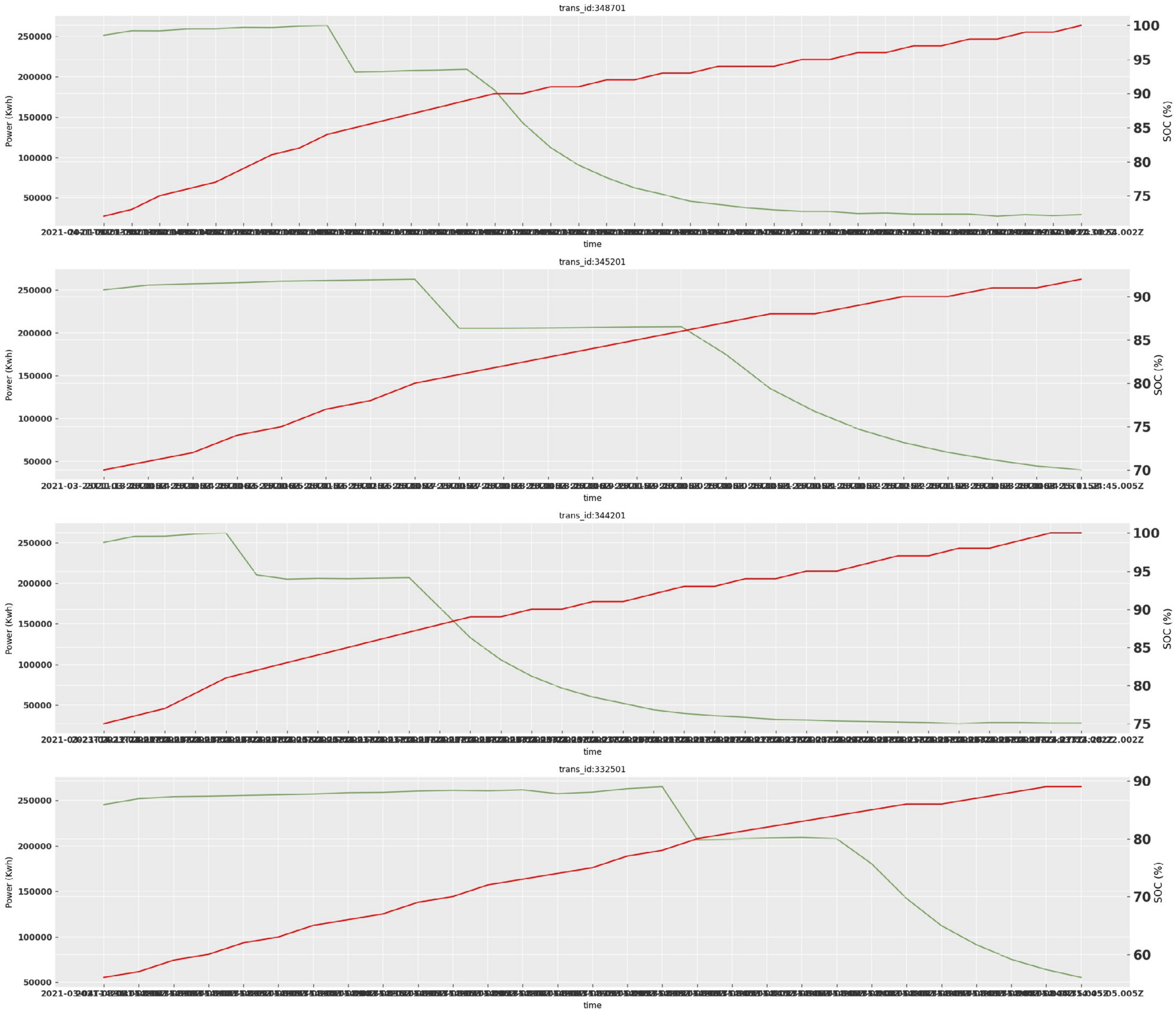
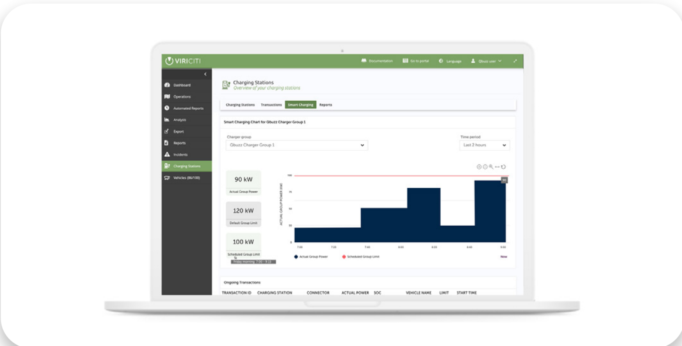


Figure 5

WANT TO LEARN MORE ABOUT SMART CHARGING?

ViriCiti Smart Charging Solutions



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Largest E-Bus Smart Charging implementation in the world

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CONCLUSION

Opportunity chargers are mostly used by operators to make sure that the buses can follow their daily schedule without the need to worry about the State of Charge and about how fast the battery is depleted. However, one should keep in mind that the higher the power of the charger, the more expensive it gets. Except for situations where vehicles need to be more resilient due to external factors - like during cold temperatures or route detours that require extra energy - using expensive, high-power chargers for charging buses that already have a high SoC value is **not the optimal solution**.

These findings suggest that we're still at the beginning of the journey to a fully integrated e-fleet charging infrastructure.

While the electrification of fleets is taking off at increasing speed, operators and bus drivers could allow for **higher Depth of Discharge** on their buses' batteries, as well as for a **better use of existing charging infrastructure**. This means there is also room for a **more efficient** driving of electric buses, translating into lower starting SoC and thus faster charging rates, leading to shorter charging sessions and better on-route recovery.

As mentioned previously, buses are currently planned very conservatively, which does reduce range anxiety. However, we see that a **more flexible** planning of bus operations is possible with an improved opportunity charging behavior. This would mean the scheduled charging sessions could be reduced, lowering the number of vehicles needed in service, which could directly lead to **costs savings**.

Intelligent telematics systems like ViriCiti's platform use **AI-powered charging time predictions** to help with the smart management of charging processes, be it on the road or in the depot. Using the data provided by such systems helps you use your existing charging infrastructure more efficiently, prioritizing chargers based on your itinerary, lowering demand costs through peak shaving, and decreasing energy costs by shifting charging times to lower energy tariffs.

Want to have a similar report tailored to your fleet? We can help.

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DEFINITIONS AND METHODS

How do we define Opportunity Charging?

In our industry, "opportunity charging" is a widely used term, generally seen as the opposite of "depot charging". However, there is no benchmark definition on what opportunity charging really is.

Opportunity charging, also referred to as "on-route charging" or "fast charging", can be simply defined as the process of a bus charging while it's on-route.

While a bus is executing its normal schedule, it can stop and charge for a short amount of time at appointed locations on the route where high-power chargers (either with a plug-in , pantograph, or wireless connection) are installed. These on-route chargers, therefore, give the opportunity for the bus to charge briefly before it continues its route[3] [4].

Thus, opportunity charging does not refer to the power of the charger or its location, but rather refers to how a charger is used by the operators to charge their vehicles. The same charger (regardless of its capacity), can be used for either slow or fast charging.

Therefore, in this report we define "opportunity charging" as charging sessions happening during regular service hours (5am-11pm) when most operators have their regular bus schedules, with a duration of maximum 60 minutes, and done through on-route chargers with a minimum power of 100KW. In the next section, we elaborate more on how and why we choose this definition.

Methods

We base our definition of opportunity charging on two important elements. First, when a bus is executing its route, and second, defining what a high-power charger is. Thus, to determine the set of chargers used for opportunity charging, we took the following steps:

STEP 1: Define what 'day' and 'night' hours are.

STEP 2: Define what 'high-power' means.

STEP 3: Exclude the chargers that have a higher average duration of charging transactions than a typical opportunity charging transaction.

STEP 1 CHARGING TIMES

Typically, most of the conventional and electric buses run throughout the day. In this report, we define the day hours as between 5am and 11pm, to match what most operators have as their regular day service hours. Therefore, we examine charging transactions that take place in this timeframe. Nevertheless, to ensure that we do not exclude chargers that have a limited amount of transactions outside this time period, we choose to examine chargers for which at least 90% of transactions occur during the 5am-11pm time period.

STEP 2 HIGH POWER CHARGERS

Secondly, for the purpose of this report, we need to define what we consider a high-power charger. As mentioned previously, there is no clear-cut definition of what high-power charger means. The power of chargers differs a lot amongst charger models and manufacturers, with typical values between 30 up to 500 KW. Additionally, there are chargers with multiple dispensers (e.g chargers with power 2x30 KW or 2x60 KW [5]) that can be used either with their single dispenser or both dispensers to charge one or two buses at the same time. As mentioned above, even 30 KW chargers can be used for opportunity charging, however the charging time increases significantly and thus these chargers are not typically chosen for this type of charging. Typical values for chargers that are used for opportunity charging are 150, 300, 350 and 450 KW chargers [6] [7] [8]. In conclusion, we look at chargers with a power of at least 100 KW. At this stage, these chargers are potential opportunity chargers.

STEP 3 DURATION OF CHARGING TRANSACTIONS

To properly identify those used mostly or solely for opportunity charging, we also analyze the duration of the transactions so that we can eliminate the chargers with an average duration of charging transactions higher than that of a typical opportunity charging transaction. For the purposes of this analysis we set a threshold of 1 hour [8]. The reason is that charging speed can differ from bus to bus, regardless of the charger capacity based on the condition of the battery. For depleted batteries, depending on how depleted a battery is, the charger capacity and the starting SoC value it can range up to that threshold.

Limitations

The opportunity charging definition set for use in the current article is not set in stone. Although the theoretical definition is easy to identify, there were choices that needed to be made during the analysis in order to pick the chargers from our database that were used as input. Having mentioned that, the current methodology captures the majority of chargers that are used for opportunity charging during daily operations. However, there are known cases - also seen in the ViriCiti database - when chargers are used both for opportunity and slow charging. For the purpose of this analysis, these chargers are excluded, but can be monitored on an individual level by operators.

REFERENCES

Kunith, A., Mendelevitch, R., Goehlich, D. (2016): Electrification of a City Bus Network: An Optimization Model for Cost-Effective Placing of Charging Infrastructure and Battery Sizing of Fast Charging Electric Bus Systems (No. 1577). Berlin. Retrieved April 30, 2021.

Abdelwahed et al. (2020): Optimizing Fast-Charging in Transit Bus Networks R2. Article submitted to Transportation Science. Retrieved September 24, 2020.

Estrada, Miquel & Mension, Josep & Salicrú, Miquel. (2017). OPPORTUNITY CHARGING OF BUSES. EFFECTS ON BUS OPERATOR COSTS AND USER PERFORMANCE.

WEBSITES

https://ipt-technology.com/case-opportunity-charging-madrid/

https://www.heliox.nl/projects/heliox-fast-charging-solution-for-volvos-first-all-electric-buses#:~:text=The%20buses%20in%20Differdange%20run,fast%20charging%20at%20end%20stops).&text=The%20charging%20system%20connects%20automatically,enables%20these%20short%20charging%20times.

https://www.oppcharge.org/

https://www.ebusco.com/charging/

https://new.abb.com/ev-charging/products/opportunity-charging

https://fastnedcharging.com/hq/everything-youve-always-wanted-to-know-about-fast-charging/

https://viriciti.com/blog/top-4-factors-that-influence-battery-degradation-in-electric-buses-how-to-avoid-them/

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