

Analysis of the peak grid load reduction using ECO-charging strategy for e-bus fleets in Gothenburg

Hasan, Mohammed Mahedi; Saez-de-Ibarra, Andoni; El Baghdadi, Mohamed; Hegazy, Omar

Published in:

2021 IEEE Vehicular Power and Propulsion Conference (VPPC 2021)

DOI:

[10.1109/VPPC53923.2021.9699184](https://doi.org/10.1109/VPPC53923.2021.9699184)

Publication date:

2021

Document Version:

Accepted author manuscript

[Link to publication](#)

Citation for published version (APA):

Hasan, M. M., Saez-de-Ibarra, A., El Baghdadi, M., & Hegazy, O. (2021). Analysis of the peak grid load reduction using ECO-charging strategy for e-bus fleets in Gothenburg. In *2021 IEEE Vehicular Power and Propulsion Conference (VPPC 2021)* (2021 IEEE Vehicle Power and Propulsion Conference, VPPC 2021 - ProceedingS). IEEE. <https://doi.org/10.1109/VPPC53923.2021.9699184>

Copyright

No part of this publication may be reproduced or transmitted in any form, without the prior written permission of the author(s) or other rights holders to whom publication rights have been transferred, unless permitted by a license attached to the publication (a Creative Commons license or other), or unless exceptions to copyright law apply.

Take down policy

If you believe that this document infringes your copyright or other rights, please contact openaccess@vub.be, with details of the nature of the infringement. We will investigate the claim and if justified, we will take the appropriate steps.

Analysis of the peak grid load reduction using ECO-charging strategy for e-bus fleets in Gothenburg

Mohammed Mahedi Hasan^{1,2}, Andoni Saez-de-Ibarra³, Mohamed El Baghdadi^{1,2}, Omar Hegazy^{1,2,*}

¹ETEC Department & MOBI Research Group, Vrije Universiteit Brussel (VUB), Pleinlaan 2, 1050 Brussels, Belgium

²Flanders Make, 3001 Heverlee, Belgium

³Ikerlan S. Coop.; José María Arizmendiarieta Pasealekua, 2, 20500 Arrasate-Mondragon, Gipuzkoa, Spain

*Corresponding author: omar.hegazy@vub.be

Abstract— Charging Management is essential in minimizing the impact on the local electricity grid when e-bus fleets become widespread in a city. With the advent of high-powered ultrafast opportunity chargers, the electricity grid can quickly become overloaded when multiple such chargers are in operation during peak hours. To be able to cope with this heavy electricity load requires either the reinforcement of the grid and the construction of extra grid infrastructure to handle the higher power load; both options are not cost effective. The cost of the electric grid infrastructure to handle fleet charging, including the high powered ultrafast DC chargers for opportunity charging, the lower powered depot chargers for overnight charging is already a significant investment for the city bus operator in terms of capital, installation, and grid connection costs, while the distribution system operator has to invest in more substation transformers and high and medium voltage grid powerlines. This paper investigates the application of the ECO-charging technique to reduce the impact on the grid and also the design of a grid-wide Charging Management System that will actively synchronize all the ultrafast chargers so that the peak load in the grid, even when multiple high-powered chargers are operating simultaneously, is significantly reduced. Utilizing active synchronization can further reduce the load by 50% or more depending on the scenario. The ECO-charging technique is based on utilizing short-duration pulsed charging followed by cool-down periods instead of charging in one continuous long-duration pulse, and it lowers the energy requirements of the vehicle by reducing the battery heat generation during high c-rate charging.

Keywords— Charging Management Strategy, ECO-charging, charger synchronization, grid impact, ultrafast chargers

I. INTRODUCTION

According to the International Energy Agency (IEA), the world electricity demand is projected to grow by 58% to 36453 terawatt-hours (TWh) by 2040, from 23031 TWh in 2018 [1]. That is a projected increase of greater than 2.6% in electricity demand every year. Of these, the share of the electricity demand coming from the transportation sector is projected to more than triple the current demand by 2040. This reflects the large-scale electrification of the transportation sector with the aim to reduce the greenhouse and other polluting emissions from internal combustion emissions (ICE) based vehicles inside urban areas. Traditionally, the electricity demand from the transportation sector came from trams and rail; however, from 2018, the demand from electric vehicles (EVs) is projected to increase by more than 23 times by 2040. The commercialization of light electric vehicles (LEVs) is well underway, and active research is underway to electrify the heavy-duty EVs, such as buses and trucks. This requires large scale investments in electric charging infrastructure, including high-powered ultrafast chargers, transformer substations, vehicle depots, high (HV) and medium voltage (MV) grid lines, and the communication network for. As part of the European Union (EU) 2050 carbon neutral plan [2], a

15-fold increase in public EV charging points by 2030 to 3 million charging points will be deployed to service a projected 44 million EVs. All these will require up to €20 billion in charging infrastructure investments over the next decade [3].

One of the problems with the deployment of a citywide ultrafast charging network is the excess demand on the electricity grid during peak hours. Charging infrastructure for LEVs do not cause problems to the electricity grid, since much of the charging happens during night or nonpeak hours, and the charging power is low. However, heavy-duty EVs feature high capacity batteries, and thus require very high-powered charger to accomplish a full charge within a reasonable timeframe. For public transport buses, the allowable charging time must respect existing bus schedules. Present-day original equipment manufacturers (OEMs) of 12m and 18m electric buses (e-bus) feature ranges of at least 200km by utilizing batteries with at least 350kWh and 550kWh batteries respectively [4, 5]. According to classification of chargers for heavy-duty EVs, the power rating of commercially available fast chargers typically ranges from 290kW to 600kW [6, 7]. A recent study conducted to determine the effects of fast chargers on the grid showed that deploying just two 600kW fast chargers or two 290kW and 450kW fast chargers can easily put up to 200A of load on a 11kV MV line [8]. To electrify all the bus routes in a city would require deploying hundreds of such high-powered chargers to cover all the bus routes or main intersection nodes. These chargers can easily overload the electricity grid during peak hours when they operate in unison.

This paper investigates, using the Use Case (UC) based on a fleet of twenty 12m buses and ten 9m buses plying three bus routes in Gothenburg, the daily impact on the grid, including the total energy consumption and the power load profile; and the reduction in the peak load using ECO-charging and charging synchronization.

II. BACKGROUND

A. Managing Grid Load

Power overloading of the electricity grid is not the only problem that can occur due to widescale implementation of high-powered charging infrastructure; according to [9], nonlinear loads, such as EV chargers, introduces power quality issues, including harmonic distortion (THD), DC offset, phase imbalance, voltage deviations and transients, and low power factor. This impact is most felt at the local feeder that supply the area where the fast charger is located. Usually, these power quality issue limits the maximum number of charging stations that can be connected to a single feeder [10]. However, advances in power electronics, converter topologies, and control methodologies have led to the reduction of the THD generated by DC fast chargers [11], and most modern power electronics devices will respect the limits of harmonics injection set by standards such as IEEE 519-1992, IEC 61000-3-12/2-4 and EN 50160:2000 [12].

The project leading to this conference paper has received funding from the European Union's Horizon 2020 Research and Innovation Program under grant agreement No 769850 (ASSURED).

This paper will try to address, using ECO-charging and active charger synchronization, the adverse impacts on the distribution network caused by overloading of the grid when many superfast chargers start operating simultaneously. Increases in the peak load of the grid can lead to imbalances, heating of the gridlines, power loss, large fluctuations in the line voltage, and to more severe problems such as brownouts and blackouts [13]. Various schemes are researched in literature to address the problems of peak load in the grid, including demand side management schemes in the form of charge scheduling, charging priority levels, and shifting the charging to outside of peak hours [14], grid reinforcement techniques using of energy storage system (ESS) backup and solar energy for power balancing [15-18], and using vehicle-to-grid (V2G) and vehicle-to-vehicle (V2V) strategies [13].

Any strategy used to solve the problem of peak grid load comes with its own sets of problems. CMS algorithms that are used to manage demand are great at lowering the peak grid load and also reduce significant fluctuations in the load; however, for public transport e-buses, these CMS do not have that much leeway to execute demand side management strategies since public transport buses run continuously throughout the day within defined schedules. Similarly, grid reinforcement is not only expensive and not always a cost-effective solution [19]. Finally, in the case of ASSURED project, which this the scope of this research, the relation between the grid and the charger is unidirectional grid-to-vehicle (G2V); thus, power balancing using V2G and V2V are not considered.

B. ECO-charging

ECO-charging is an intelligent charging method that can improve battery longevity, minimize the peak load on the grid, and lower cost. It accomplishes this by limiting the charging c-rate, not charging a battery to full capacity, employing

flexible charging behavior, and scheduling, or obtaining charging energy from renewable sources when possible [14, 15]. ECO-charging as a component of smart charging strategy relies on accurate forecast of both the supply side (i.e., the energy mix and tariffs) and demand side (i.e., predictive demand and energy storage capacity) during charging. In [20] a novel strategy of ECO-charging, using pulsed charging, was introduced that reduced the need for active battery cooling during charging; the charging strategy (CS) also maximized the duration of overnight charging by allowing the state of charge (SoC) of the ESS to drift down throughout the day towards the lower bound set by the OEM. Figure 1 illustrates the concept of ECO-charging based on pulsed charging more clearly. This was not only effective in reducing the vehicle energy requirements, but also the average load on the grid during peak hours. The optimum charging-to-cooldown ratio and the optimum charging pulse was found using brute force method to determine the lowest cooling energy consumption for a variety of charging rates. Results showed that up to 5% reduction in vehicle's energy consumption can be achieved due to implementation of ECO-charging technique. In [8], it was further shown that applying ECO-charging to more than one chargers that are active simultaneously leads to passive synchronization that further reduced the average load on the grid; the paper defined synchronization as when during pulsed charging, the charging pulse of one charger falls within the cooldown pulse of another charger. Results showed that ECO-charging pulses are effective in reducing the peak load in the grid by 10%.

Figure 1 highlights the main difference between normal charging strategy and the ECO-charging strategy and the impact on SoC and battery temperature. The simulation was carried out for Gothenburg during January (mid-winter) to analyze for the worst-case energy requirements. The high temperature was 20C, and the low temperature was -20C.

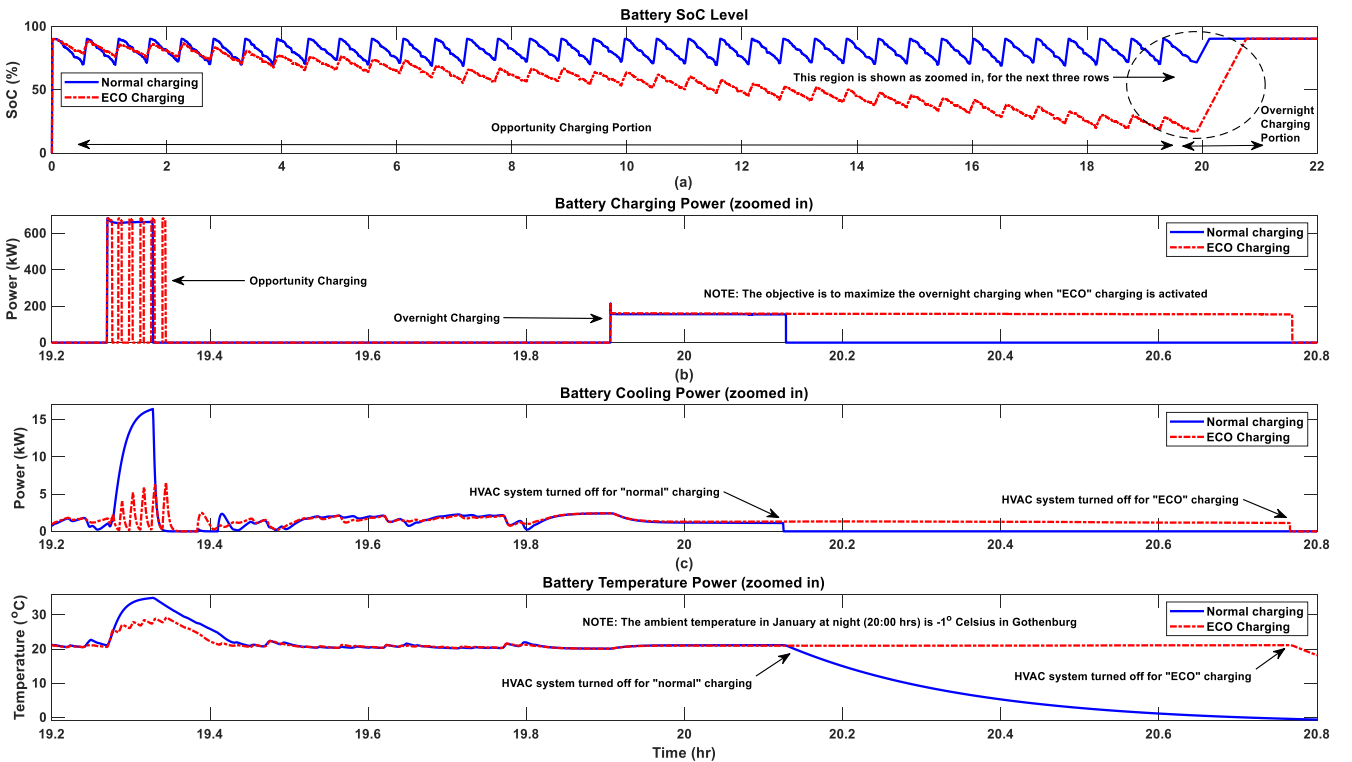


Fig. 1. Differences between normal charging and ECO-charging on (a) battery SoC, (b) charging strategy, (c) required cooling power, and (d) battery temperature

In this paper, the CMS for active synchronization between multiple chargers, employing ECO-charging, will be presented using a UC involving six opportunity chargers in Gothenburg city to determine the extent of the reduction of the peak load on the grid. Backend communication between chargers in a smart grid is key to achieving synchronization.

III. DESCRIPTION OF THE USE CASE

A. The Simulation Platform

The UC simulations are carried out in the simulation platform that is described in detail in [8, 20]. It is a versatile tool that allow the user to easily create bus fleets plying multiple routes in each city. The simulation platform designed in MATLAB/Simulink allows the user to configure the route operational and charging scenario, the city's climate using graphical user interface (GUI). The simulation platform allows the user to deploy the appropriate number of buses and charging infrastructure in each route and the interaction between the charging infrastructure and the buses. The simulation platform outputs various measurements as plots, including for the battery, the power electronics, the electric motor, vehicle kinematics, and the grid. Using MATLAB scripts, the user can easily configure the vehicle and charging parameters. Finally, the simulation platform also gives information useful to the bus operator, such as the average fleet total cost of ownership (TCO), the average fleet energy utilization, and the daily energy consumption by the fleet.

B. Description of the Operational Scenario

This section provides a brief overview of the cities and the routes, as well as the electric buses that will be simulated in the simulation platform. The UC is described for three bus routes in the city of Gothenburg, Sweden during the month of January. January has been selected because, the operational energy utilization is the greatest during this month according to [8], thus needing a large amount of charging throughout the day. Gothenburg has a cool temperate and oceanic climate, with mild summers and cold winters; the city experiences plenty of rainfall throughout the year; being a coastal city, the diurnal temperature variations are moderate.

TABLE I. OPERATIONAL AND CHARGING REQUIREMENTS

Parameters	Route R55	Route EL16	Route R50
Operational requirements			
Bus type	Type II	Type II	Type I
Operational time	13hr, 167km	20hr, 396km	13hr, 295km
Bus Frequency	Every 10 mins	Every 5 minutes	Every 18 minutes
Average speed	18.24 kph	23.57 kph	50.6 kph
Return trip distance	15.2km	22km	27.8km
Number of return trip	11	18	11
Number of buses	7	13	4
Charging requirements			
Opportunity chargers	2	2	2
Charging power	290kW	450kW	600kW
Charging duration	Up to 10 mins	Up to 5 mins	Up to 15 mins
Overnight chargers	1	2	1
Charging power	150kW	150	150
Charging duration	Up to 10hrs	4 to 5 hrs	Up to 10hrs

TABLE II. VEHICLE PARAMETERS FOR 9M AND 12M BUS

	Type I	Type II
Vehicle Parameters		
Dimensions (m)	8.61 x 2.967 x 2.5	12 x 3.3 x 2.55
Empty mass (t)	8.9	11.9

Maximum mass (t)	14.2	19
Gearbox Parameters		
Final gear ratio		5:77
Gear efficiency (%)	97	97
Electric Machine Parameters		
Motor type	Permanent magnet	Permanent magnet
Cont. power (kW)	400	185
Base speed (rpm)	7200	4200
Max torque (Nm)	530	425
Efficiency (%)	LuT	LuT
Max DC Link (V)	660	660
Min DC Link (V)	420	420
Energy Storage System Parameters		
Cell technology	LFP	LFP
Capacity (Ah)	336	336
Max SoC (%)	90	90
Min SoC (%)	10	10
Usable energy (kWh)	160	160
Max Voltage (V)	768	768
Min Voltage (V)	422	422
Max charge rate	3.75C	3.75C
Max discharge rate	7.5C	7.5C
Mass (kg)	1440	1440
Auxiliary Parameters		
Voltage (V)	600	600
Power (kW)	15	28
Operational Parameters		
Max speed (km/h)	80	80
Annual distance (km)	45000	45000

Table I and II describes the operational requirements of the three routes in Gothenburg and provides details about the vehicle that will be plying these routes that will be input into the simulation platform.

Route EL16 runs between Eriksbergstorget to Sahlgrenska Sjukhuset, it has a route length of 11km, and a return trip takes approximately 56min. Route R55 is a subset of route EL16, it runs between Teknikgatan and Sven Hultin Plaats, it has a route length of 7.6km, and a return trip takes approximately 50min. The buses traveling in route EL16 travel on average more than 5km/h faster than the buses traveling in route R55, which indicates that route EL16 is composed of a slow moving traffic on the portion that is similar to route R55, and very fast moving traffic in the remaining portion of route, indicative of a highway. Thus, route R55 is completely urban, while route EL16 has some suburban parts. On the other hand, route R50, between Frolunda and Kalleback, is probably an express intercity route, whose main portion of travel is in the highway; thus, the average speed of the route is high. All three routes contain two opportunity chargers at either ends of the route; however, each route's charging power is different.

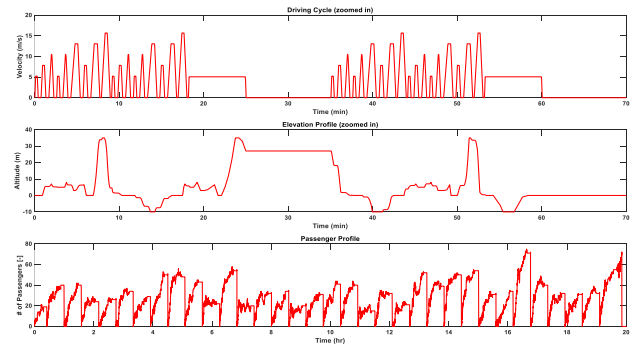


Fig. 2. Scenario inputs, including the driving profile (top row, showing for one return trip only), the elevation profile (middle row, showing for one return trip only), and the passenger profile (bottom row, showing for full day) for the fleet simulation (NOTE: showing the representative for one route only)

Since exact measurement data was not available for the three routes, assumptions are made for the driving cycle, the route elevation profile, and the passenger profile. As shown in Figure 2, the hybrid SORT profile is used for the driving cycle, a random passenger profile is used, while a random repeating sequence is used for the route elevation profile.

IV. CHARGING MANAGEMENT AND STRATEGY

This section will briefly describe the algorithm to be utilized for synchronizing multiple chargers employing ECO-charging. Figure 3 illustrates the UC scenario of four opportunity chargers active within the same grid [8]. When the chargers are charging in the normal mode, the chargers output

a continuous DC current to the battery if it is in the constant current charging phase. In normal mode charging, when multiple chargers are active simultaneously, the total current experienced by the grid is the sum of their individual currents. On the other hand, when ECO-charging is activated, the constant current is replaced by pulsed current, then at the individual charger level, the average current drawn from the grid has already lowered, as seen in Figure 3. Furthermore, when considering groups of chargers, if the charging pulses are active simultaneously, then the situation is similar to normal mode charging; however, if the pulses are active at different times, then the total peak current experienced by the grid is lesser.

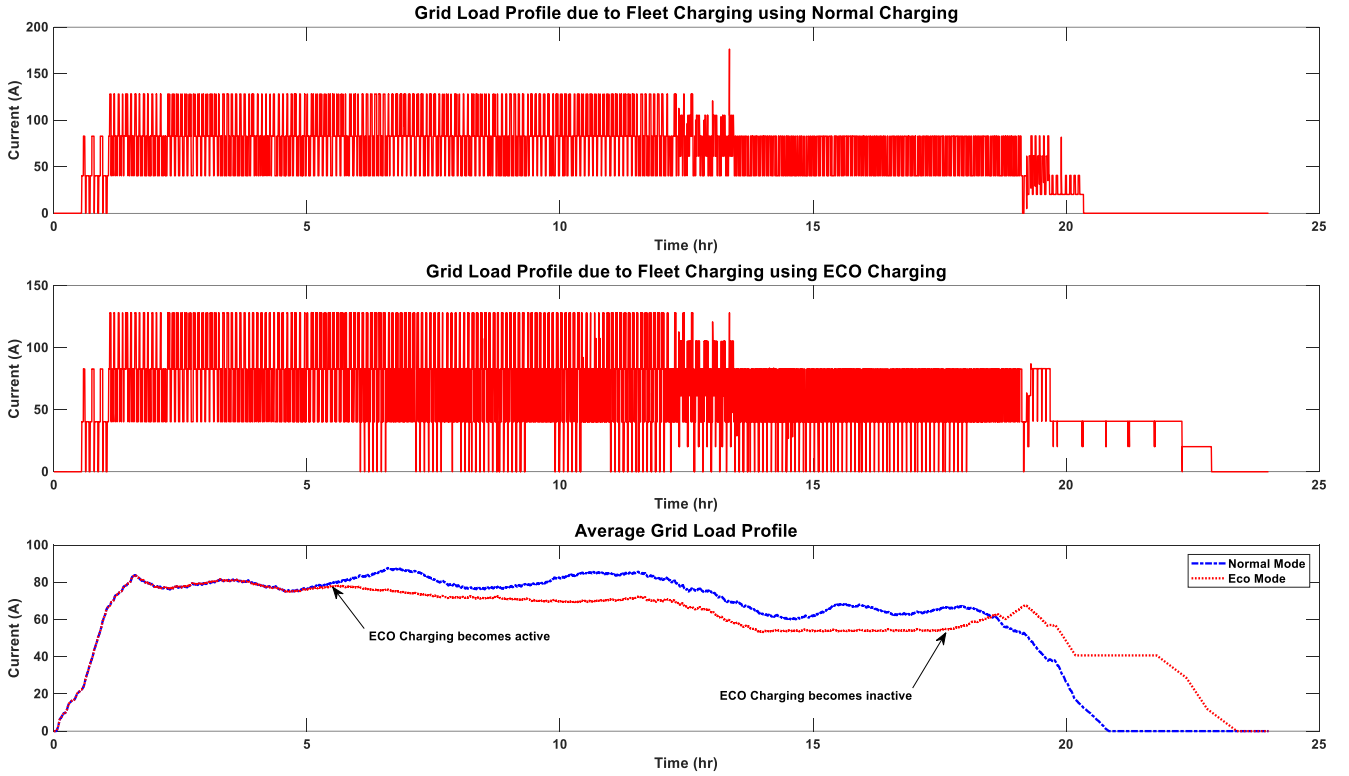


Fig. 3. The effect on the grid due to applying ECO-charging [8]

In passive synchronization, multiple pulses can be active simultaneously or at different times through mere probability. However, to ensure that the maximum number of charging pulses are active at different times from each other would require active synchronizations, by shifting the phase of each pulse relative to each other. To test the methodology thoroughly, another route with its own set of opportunity chargers will be added to the fleet model from [8].

A. Active Synchronization Methodology

Modern chargers do not act individually; they are part of a large charging network or the smart grid. Modern chargers usually have several means of connectivity, including Ethernet, 3G or 4G, Wifi, and Modbus TCP/RTU to name a few [21]. Protocols such as open charge point protocol (OCPP) and open charge point interface (OCPI) are means for backend communication, using a shared language, between chargers and charging station management systems (i.e., a centralized charging controller) [22]. These protocols standardize communication so that products from different vendors have no difficulty communicating, and OCPI allow communication between the charging hardware and the cloud. A central manager or peer-to-peer (P2P) exchange between

chargers can enable the required messaging and communication necessary to achieve active synchronization.

In [20], it is shown that the most optimal duty cycle for the charging pulse was 30%. Thus, three chargers can group together during a synchronization, and the output of all three combined when ECO-charging activated should be equivalent to the output of only one charger. A P2P messaging format is implemented in the simulation platform to achieve synchronization, according to the following rules:

- Any three chargers can form a synchronized group with each other.
- The grouping will work as first come, first serve basis; a charger can join a group as long as it is not full.
- Once three chargers form a group, it is full, so the next charger will form a new group.
- The first charger in the group will not have any change to the timing of its pulse, the second charger in the group will have its pulse shifted by 120 degrees, while the third will have its pulse shifted by 240 degrees.

- A charger can leave its group any time it has finished with charging.
- The groupings are variable; joining a group do not limit a charger only to that group. When a charger becomes active, it joins the next available incomplete group, or if no incomplete group is available, create a new group.

B. Messaging Format

Proper messaging is essential to ensure that the chargers are aware of the existence of prior synchronized groups, and if there is space in the group to join. In real life, messaging between chargers would follow standard protocols involving proper handshaking between chargers to prevent congestion and the use of checksum to ensure data integrity [23]. Common communication and signaling standards dealing with EV charging can be found in [24, 25]; however, these standards deal with communication between EV and charger, or between charger and grid, or for the purpose of billing and accounts. OCPI can be used to connect the charger to the cloud, and SCADA can be used for remote supervisory control; however, all these are examples of top-down hierarchical approach to communication. To enable P2P communication between chargers, new protocols would need to be developed.

In the simulation, it is assumed that networking requirements are taken care of behind the scene; thus, a simple messaging structure will be used to communicate between the chargers. To enable synchronization, there needs to be a way for a charger to determine the existence of prior groups, to determine if there is a space available in a group for a charger to join, and which position in the group should it join as. Thus, the message format is as follows:

$$[[group\ ID|\# \text{chargers}|index|chargerID]] \quad (1)$$

Other chargers searching for a group to join would check if the number of chargers < 3, and if so, join the group with index = 0, 1 or 2, depending on which is available, starting with the lowest, and increment the number of chargers by 1. If the group is full, i.e., if the number of chargers = 3, then a charger will create a new group with the index = 0, number of chargers = 1, and the group ID = lowest number that is not taken, starting from 1. A group ID of 0 indicates that the charger is not part of any group, or not charging at the moment. Every opportunity charger will have a unique ID ranging from 0 to 5 for the six-opportunity charger in the fleet simulation. Once a charger is finished with charging, it can leave the group by decrementing the number of chargers by 1 and set its group ID to 0.

The second aspect of the messaging has to do with the timing within a group, that will phase shift the charging pulses accordingly. The message format is as follows:

$$[[groupID|chargerID|index|period|pulse]] \quad (2)$$

Period is the timing value that is output by all chargers based on their own internal ECO-charging pulse timer and can range from 0 to 50. The value of the period is only valid if the charger is active and provides the timing for the other chargers in the group that are inactive; the period value of an inactive charger is ignored. Pulse indicates the status of the charger; it is a Boolean value that will show as 1 if the charging pulse is active. Other chargers in the group will monitor is signal; as long as it is high, the other chargers in

the group must remain in cooldown mode by forcing a delay to their own charging pulse, if necessary. The delay, T_d , is calculated as follows:

$$T_d = \begin{cases} (index_C - index_A) * 15 - period, & \text{if } C > A \\ (3 + index_C - index_A) * 15 - period, & \text{if } A > C \end{cases} \quad (3)$$

Where $index_A$ is the index of the active charger and $index_C$ is the index of the charger in question.

Once the pulse status of the active charger becomes low, then the other chargers in the group will decide who will become active based on the following criterion:

$$index_N = \begin{cases} 0, & \text{if } index_A = 2 \\ 1, & \text{if } index_A = 0 \\ 2, & \text{if } index_A = 1 \end{cases} \quad (4)$$

Where $index_N$ is the index of the next charger to become active. Equation (4) is the case when there are three chargers in the group, if there are only two chargers in the group, then the $index_A$ will simply flip between the two chargers.

C. Expected Results

There are six opportunity chargers that will employ ECO-charging; thus, there can be a maximum of two groups of three chargers that are synchronized. For the fleet simulation, there are a total of six high-powered opportunity chargers, including a pair of 290kW, 450kW, and 600kW chargers respectively. With this being the case, it is expected that the worst case load on the grid will be when the 600kW chargers are in different synchronized groups; in such a case, a peak load of 109A will be put on the grid. This is less than half of the peak worst-case load of 243A without any synchronization. Furthermore, assuming all charger groupings are equally possible with active synchronization, there will be peak difference in the load of 83A, and a mean load 65A with a standard deviation of 24A. In the final version of this paper, proper analysis will be provided.

V. CONCLUSION

The paper provides an ECO-charging methodology as a form of charging management that is useful in reducing the vehicle auxiliary energy requirements, reducing the average load on the grid, reducing the peak load on the grid, and reducing the peak difference in the load, i.e., eliminate wide scale load fluctuations in the grid. ECO-charging can reduce vehicular energy demand by 5%, the average load on the grid by 10%; and when multiple chargers employing ECO-charging are actively synchronized, it can also reduce the peak grid load by more than 50%, when compared to non-synchronized charging.

ACKNOWLEDGMENT

The authors acknowledge Flanders Make for their support to this research group.

REFERENCES

- [1] IEA (2019), World Energy Outlook 2019, IEA, Paris, Ch 6.3, pp 261, URL: <https://www.iea.org/reports/world-energy-outlook-2019>, last updated in 21/11/2019, accessed on 15/06/2021
- [2] Website: "A European Green Deal | European Commission", URL: <https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal-en>, last updated on 20-05-2020, accessed on 15/06/2021
- [3] L. Mathieu, J. Poliscanova, C. C. Ambel, N. Muzi, S. Alexandridou, "Recharge EU: How many charge points will Europe and its member states need in the 2020s", in TE Infrastructure Report, European Federation for Transport and Environment, January 2020

- [4] Website: New batteries and longest bus so far from Solaris - electrive.com, URL: <https://www.electrive.com/2019/10/19/new-batteries-and-longest-bus-so-far-from-solaris/>, last updated on 19/10/2019, accessed on 15/06/2021
- [5] Website: BYD Presents 12-Meter eBus With All-New Aluminium Body (insideevs.com), URL: <https://insideevs.com/news/354985/byd-12-metre-ebus-aluminium-body/>, last updated on 18/06/2019, accessed on 15/06/2021
- [6] Website: Design of Charging Infrastructure for Electric Buses • EVreporter, URL: <https://evreporter.com/charging-infrastructure-for-electric-buses/>, last updated on 03/05/2020, accessed on 15/06/2021
- [7] Website: Charging Infrastructure for Battery-Electric Buses (nema.org), URL: <https://www.nema.org/blog/view/2020/05/26/charging-infrastructure-for-battery-electric-buses>, last updated on 26/05/2020, accessed on 15/06/2021
- [8] M. M. Hasan, N. Avramis, M. Ranta, A. Saes-de-Ibarra, M. El-Baghdadi, O. Hegazy, "Multi-objective energy management and charging strategy for electric bus fleets in cities using various ECO strategies", in *Journal of Sustainability*, MDPI 2021, "in press"
- [9] R. Bass, N. Zimmerman, "Impacts of electric vehicle charging on electric power distribution systems", in *Technical Report, Transportation Research and Education Center, OTREC-SS-731* (2013), <https://dx.doi.org/10.15760/trec.145>
- [10] Y. Ligen, H. Vrabel, H. Girault, "Local energy storage and stochastic modeling for ultrafast charging stations", in *Journal of Energies*, MDPI, 2019, 12, 1986, doi:10.3390/en12101986
- [11] S. Chakraborty, H. N. Vu, M. M. Hasan, D. D. Tran, M. El Baghdadi, O. Hegazy, "DC-DC converter topologies for electric vehicles, plug-in hybrid electric vehicles and fast charging stations: state of the art and future trends", in *Journal of Energies*, MDPI 2019, 12(8), <https://doi.org/10.3390/en12081569>
- [12] C. K. Duffey, R. P. Stratford, "Update of harmonic standard IEEE-519: IEEE recommended practices and requirements for harmonic control in electric power systems," in *IEEE Transactions on Industry Applications*, vol. 25, no. 6, pp. 1025-1034, Nov.-Dec. 1989, doi: 10.1109/28.44238
- [13] W. Khan, F. Ahmad, M. S. Alam, "Fast EV charging station integration with grid ensuring optimal and quality power exchange", in *Journal of Engineering Science and Technology*, 22(1), 2019, pp. 143-152, ISSN 2215-0986, <https://doi.org/10.1016/j.jestch.2018.08.005>
- [14] F. Ahmad, M. S. Alam, "Optimal sizing and analysis of solar PV, wind, and energy storage hybrid system for campus microgrid." In *Journal of Smart Science* 6(2), 2018, pp. 150-157
- [15] H. Zhao, A. Burke, "An intelligent solar powered battery buffered EV charging station with solar electricity forecasting and EV charging load projection functions", in *proceeding of 2014 IEEE International Electric Vehicle Conference (IEVC)*, pp. 1-7
- [16] S. Negarestani, M. Fotuhi-Firuzabad, M. Rastegar, A. Rajabi-Ghahnavieh, "Optimal sizing of storage system in a fast charging station for plug-in hybrid electric vehicles", in *journal of IEEE transactions on transportation electrification* 2(4), 2016, pp. 443-453
- [17] J. Deng, J. Shi, Y. Liu, Y. Tang. "Application of a hybrid energy storage system in the fast charging station of electric vehicles", in *journal of IET Generation, Transmission & Distribution* 10(4), 2016, pp. 1092-1097
- [18] T. Dragičević, S. Sučić, J. C. Vasquez, J. M. Guerrero, "Flywheel-based distributed bus signalling strategy for the public fast charging station", in *journal of IEEE transactions on smart grid* 5(6), 2014, pp. 2825-2835
- [19] M. Andersson, "Energy storage solutions for electric bus fast charging stations: cost optimization of grid connection and grid reinforcements", *Masters Thesis, Uppsala Universitet*, 2017, ISSN: 1650-8300
- [20] M. M. Hasan, M. Ranta, M. El Baghdadi, O. Hegazy, "Charging management strategy using ECO-charging for electric bus fleets in cities", in *proceeding of 2020 IEEE Vehicle Power and Propulsion Conference, VPPC 2020, Gijon, Spain*
- [21] Website: Advance | Nexttender solution | Powerdale, URL: <https://www.powerdale.com/en/product/advance>, accessed on 15/06/2021
- [22] Website: OCPP 2.0.1, Protocols, Home - Open Charge Alliance, URL: <https://www.openchargealliance.org/protocols/ocpp-201/>, accessed on 15/06/2021
- [23] Website: A Primer on Network Communication - Tutorialspoint, URL: https://www.tutorialspoint.com/python_penetration_testing/python_penetration_testing_primer_on_network_communication.htm, accessed on 15/06/2021
- [24] P. Rademakers, P. Klapwijk, "EV related protocol study – v1.1", study report by ElaadNL, 2016
- [25] R. Pratt, F. Tuffner, K. Gowri, "Electric vehicle communication standards testing and validation – SAE: J2847/1, PNNL-20913, US DoE report prepared by Pacific Northwest National Laboratory 2011