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EV's as energy storage on urban light rail systems — A synergy of requirements

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Abstract

The increasingly urgent need to decarbonize transport is leading to a much greater uptake of electric vehicles (EVs) in countries across the world. Also, the installation and use of urban light rail systems (trams) is seen as a way of breaking the reliance of commuters on the internal combustion engine, and therefore car ownership. Due to the simplicity of design, most conventional tram systems use unidirectional substations to draw power/energy from the utility supply. Due to their very nature, the substations are not able to return excess regenerated energy from the trams back into utility supply, with this energy often being dissipated in dump resistors onboard the trams to prevent over-voltages on the tram system. This paper explores the possibility of using EV's as temporary trackside energy storage systems on urban light rail systems through the use of bi-directional connection interfaces (chargers), which allow use of the vehicle battery in typical V2X scenarios. The paper uses the city of Sheffield (UK) Supertram network as an example network on which the effect of EV energy storage could be studied.

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Keywords: Light rail; Electric vehicles; V2X; Energy storage

1. Introduction

The UK government, in a similar manor to other governments around the world, has promised to reduce UK carbon emissions to at least 80% below their 1990 level by 2050 [1]. To date, 2021, the UK has already cut carbon dioxide (CO_2) emissions by 47% [2]. One key target for this carbon reduction is the electricity generation industry, where the increase in renewable generation is making improvements in the carbon foot print of the energy network. One major area responsible for CO_2 emissions is the transport sector which contributed 32% of the country's overall CO_2 emissions in 2021 [3]. Therefore to meet the overall carbon reduction targets it is critical to decarbonize the transport sector. To this end, the electrification of road and rail transport, to take advantage of the increasingly low

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carbon electricity generation, is one of the most promising measures for carbon emission reduction [4,5]. Passenger travel in the UK already accounts for more than 98.3% of electricity consumption on the mainline rail network [6], and the passenger travel by light rail, tram and metro are all powered by electricity [7–17], as the UK mainline rail and tram/metro networks are already well electrified. As the peak operating periods for light rail coincides with the utility peak demand periods (approximately 07.00 to 20.00), [18], light rail networks increase the stress on the electricity supply when it is least welcome. Additionally, most light rail (tram) systems are designed to minimize cost, and therefore suffer from wasting regenerated energy due to tram braking, as the tram system supply substations are predominantly simple rectifiers, and hence are unidirectional. Any energy recovered by an individual tram is initially returned to the tram network to be used by other tramcars within the same supply section, but in modern urban light-rail systems, where the distance between stops is relatively short, leading to more frequent braking events, significant energy can be lost due to the lack of other trams in the section [19]. There are a number of papers discussing the use of trackside energy storage systems (ESS) as a method of reducing energy loss through improved energy recovery and re-use [20–28], however the high capital costs of such trackside storage reduces the economic feasibility of these systems [23–27].

In addition to the moves towards increased carbon reduction from light rail networks, the push towards EVs forms a key component in the electrification of road transportation. The concept of vehicle to grid (V2G) is not new, utilizing the energy storage in EV batteries to supply energy to the grid at times of peak stress, [29,30], however this concept can be expanded to V2X where the energy stored in EV's can be exported to other markets [31–33]. The recent growth in EV ownership, pushed by legislation, has led to an explosion in EV ownership in the UK, rising to ∼375k EVs in the last quarter of 2020, with 80,000 ULEVs being registered for the first time in 2019 [34,35]. Given the introduction of legislation to ban the sale of petrol and diesel powered cars by 2030 to support the decarbonization of road transport, the numbers of available EV's is expected to increase significantly [36]. The increasing numbers of EVs require a robust and significant charging network, which is sometimes difficult to provide in urban environments where the electricity supply networks are already at capacity. The use of urban light rail networks to provide charging of EV's at locations within a city, and the use of the EV's as trackside energy storage to capture regenerated energy from trams leads to a win–win scenario, increasing the availability of EV charging, whilst improving the efficiency of the urban light trail systems. Recent research also predicts the potential economic benefit of utilizing the EV rather than conventional ESS for a typical light-rail system [37]. However, this connection and integration of EVs to tram systems has not yet been thoroughly explored based on typical system operation. This paper explores the hourly energy balance of an urban light rail system (tram network) and demonstrates the impact of the use of EV's as the only energy storage element within the tram network. The reduction in energy drawn from substations, together with the reduction in energy dissipated in tram dump resistors is used to determine the success of the proposed system.

2. Tram system energy use

The biggest difference between using a standard trackside ESS and an ESS based on a combination of EV's is the variability introduced through the mobility of the EVs. For example, the number of EVs connected to the track at any given time will be variable, dependent on time of day, both in terms of the car-park operating hours, and driver requirements. Also the duration of stay of a given EV may vary between the whole day in the case of commuting, and maybe only 1–2 h for a shopping trip. It is therefore essential to understand the baseline energy requirements and use of the tram system to determine the impact of the EV based ESS.

2.1. Target tram system

The work in this paper is based on the Sheffield Supertram System in the UK city of Sheffield. This is a typical urban tram system comprising of 3 lines, the Blue line, the Yellow line and the Purple line. Each line caters for outward and inward travel to the city center, with the whole tram system comprising of 48 stops and 12 supply substations. As the substations are collocated with some of the tram stops, they are named accordingly. Fig. 1 illustrates the entire tram system, showing the relative location of the substation and stops.

Within the Supertram network, the substations are fed with 11 kVac from the utility supply, which once transformed is rectified to a 'standard' 750Vdc for supply to the network. Each substation uses a bilateral approach, in that each substation supplies power to the adjacent rail supply sections. The 12 substations on the network

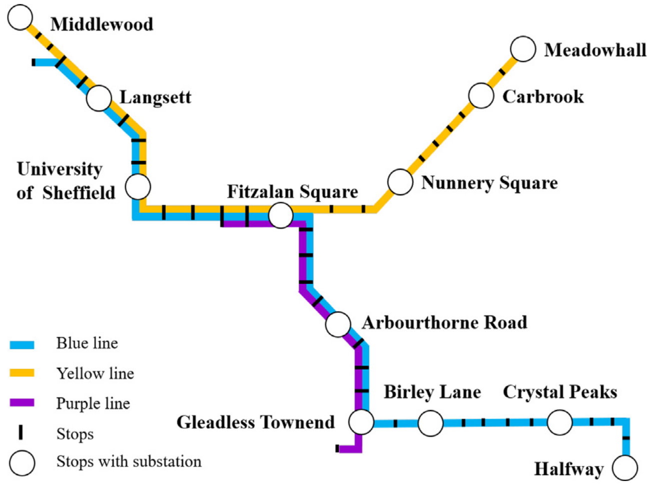

Fig. 1. Sheffield Supertram Route Map.

therefore divide the whole system into 11 power supply sections. The whole network uses a common overhead catenary system (OCS) to supply the energy to the individual trams on the network [37]. The term 'Common' OCS comes from the same cable being used to supply the outward and inward tracks within a supply section, therefore any tram on the outward track may pick up regenerated energy from a braking tram on the inward track, and vice-versa. In systems such as the Sheffield Supertram, it is common for the substations to comprise of unidirectional rectifiers such that energy generated by the braking trams cannot be fed back into the utility supply. To this end, any regenerated energy from decelerating trams is fed back into the supply section of the tram system and may be picked up by other trams within the same section. However if no trams are present in the same section as the decelerating tram, the energy being returned to the track/catenary causes the voltage on the catenary to rise as the inherent capacitance of the system is charged. To prevent dangerous over-voltages on the tram network, each tram can detect the voltage on the system and is equipped with dump resistors on the roof of the tram to dissipate excess energy and prevent excessive system voltages through resistive dissipation and voltage clamping. Providing a path for this energy, through which it can be reused instead of being dissipated, gives a route to improving system energy efficiency and additionally, can provide a method for EV charging.

2.2. Stem energy use

The energy use of the tram system was calculated from the tram operating parameters, measured operating profiles and overall system timetable. Measured operating data suggests that the characteristics of an individual journal remains broadly the same as other journeys carried out at similar times of day and days of the week. The operating profiles also show that, as Supertram operates a 'stop by request' system, during off-peak hours some stops are omitted from journeys due to lower passenger numbers. This gives rise to the need for the definition of a peak operating period and an off peak operating period. These are based on typical recorded data from journeys carried out during these periods and can be referred to as the Peak Period Operation Data (PPOD) and the Off Peak Operation Data (OPOD). The operating periods are thus defined as:

- Peak Period: 07:00 to 20:00
- Off-peak Periods: 05:00 to 07:00 and 20:00 to 1:00 (+1)

To obtain the tram operation data, a number of individual journeys were logged using GPS equipment, giving rise to Distance, Velocity and Acceleration data for the journey. A number of journeys were logged, during both peak and off-peak periods to obtain two sets of data. These datasets include data from every line in the network across a whole day of operation. To illustrate the differences between peak and off peak periods, Fig. 2 shows the velocity profiles for journeys between the Gleedless Townend tram stop and the Halfway tram stop on the Supertram

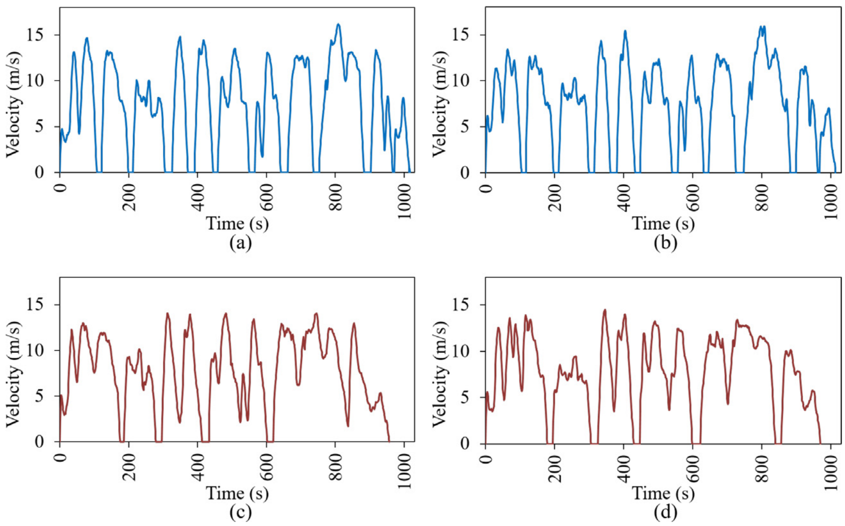

Fig. 2. Velocity profiles for journeys between halfway tram stop and Gleedless Townend tram stop on the Supertram network. (a) and (b) – Peak period, (c) & (d) – Off-peak period.

network. Fig. 2(a) and (b) show data for different peak period journeys, whilst 2(c) and (d) show comparable off-peak journeys. Similarities can be seen between the two journeys within the same periods, but distinct differences appear between the peak and off-peak periods.

Work here builds on previous publications by the authors where models of the overall tram system were developed in the MATLAB and Simulink environments, and therefore readers are directed to those to avoid excessive duplication here [37,38]. From the tram operational datasets and the published timetables, an hourly energy usage graph can be constructed, shown in Fig. 3.

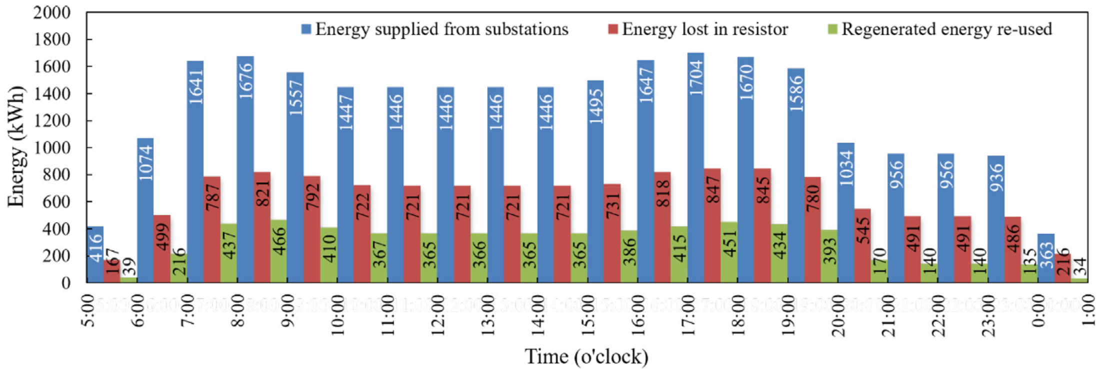

Fig. 3. Hourly energy use within the Supertram network.

This accounts for energy delivered from substations, energy lost in the on-board dump resistors and regenerated energy actually picked up by other trams within the network where possible. There are a number of points of interest which may be observed in the figure:

- There is a correlation between the energy drawn from substations and the energy lost in the dump resistors, with typically half of the energy supplied by the substations being lost in the dump resistors.
- Peak periods require more energy than off-peak periods, as more frequent operations in the peak periods and higher passenger numbers (load) contribute to a higher energy demand.
- The time when EV's would most likely be parked in park-and-ride facilities next to the tram stops closely matches the peak operating periods, as would be expected from normal commuter behavior.

3. Proposed EV storage system

Trackside energy storage systems are conventionally comprised of stationary batteries, or occasionally, flywheels. These act as energy storage of a fixed and defined capacity. Here, these will be referred to as a Stationary Energy Storage System (SESS). This paper presents an approach to the use of EV's as trackside storage, being a purely EV based energy storage system (EVESS), which will be of variable storage capacity dependent on the availability of EV's on the system.

3.1. EVESS simulation

Whilst the standard SESS was described in detail in previous publications [38], the EVESS comprises 3 distinct sections, as illustrated in Fig. 4.

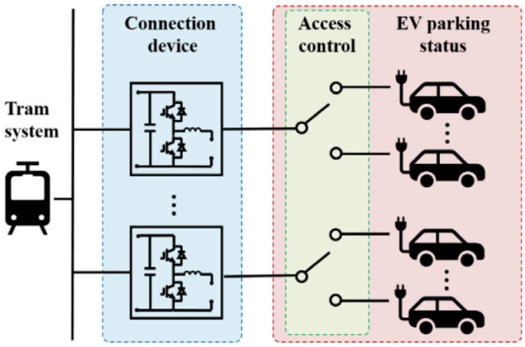

Fig. 4. EVESS Structure/configuration.

Here it may be seen that the parked EV's are interfaced to the DC side of the tram system via dc–dc, bi-directional chargers, allowing:

- The EV's to be charged when no tram is present on the section they are connected to.
- The EV to absorb the tram regenerated energy on deceleration.
- The EV to support the energy requirements of the tram during acceleration, lowering the energy drawn from the utility supply via the substations.

Two Key differences between a standard SESS and the EVESS are:

- A SESS only requires a single connection converter between the energy store and the track, whereas the EVESS requires and interface device (charger) per vehicle
- The storage capacity of the SESS is known and defined, whereas the available storage capacity of the EVESS is time dependent as vehicles arrive and leave, and are temporarily connected to the tracks.

To model the temporal availability of the EVESS storage components, the connection device module is tasked with acting as an access control module, to control the size and availability of multiple energy storage units on the system, mimicking the arrival and departures of EVs within the system.

3.2. EV parking status

The EV parking status, and hence the capacity of the available energy store is impacted by both the length of time a given EV is parked at the charger, and the number of EVs available at any given time. To simplify the variables, the EV availability is taken in 1 h slots, to match the simulated tram system energy use. Therefore as an example, for any given 24 h period, if each EV connects to a single charger for 2 h, the charger can accommodate a maximum of 12 EVs in sequence. Similarly, if the EV's park for a period of 6 h each, a single connection can only accommodate 4 EVs in sequence.

In this paper, the scenarios considered are that the EV's are available between normal working hours (08.00 to 18:00), during which time they are available to be utilized on the tram system as storage. As the section being studied initially is between Carbrook tram stop and Nunnery Square tram stop, which has a large shopping center at the middle of the section with a large car park, it is assumed that the EVs will be available for 2 h at a time, commensurate with a usual stay at a shopping center. This reflects well an ideal location where such a system could be located on the tram network.

3.3. EV battery/vehicle availability

A further important consideration with respect to the energy storage ability of the system is the size of the individual EV batteries. To simplify the simulations, all batteries were assumed to be 100 Ah (39 kWh), and be limited to a typical maximum charge rate of 2 C for the battery capacity. This is commensurate with a typical Nissan Leaf EV battery, and the typical maximum charging rates for Lithium ion batteries to prevent thermal issues and overheating/degradation. As it is not known at what state of charge (SoC) an EV battery would have on arrival, for the purposes of this work, it has been assumed that all EV's arrive with an initial SoC of 50%, and that the battery will not be charged beyond 95% to prevent overcharge and balancing issues within the packs.

In addition to the battery capacities assumed for the work, the availability of individual batteries is also critical to the system operation. The EV availability takes the form of both the individual EV parking times, and total number of EV's parked at any one time. To achieve variations, the EV parking time was assumed to be either 2 h, 5 h or 10 h for the EV's, and for the total number of EV's available/parked, we assume two scenarios: the first being where only a single EV is parked on a given day, occupying a single charger for its availability period, and the second being where there are sufficient EV's available to fully share the nominal 10 h parking period between them. In total this leads to 5 possible scenarios, illustrated in Fig. 5.

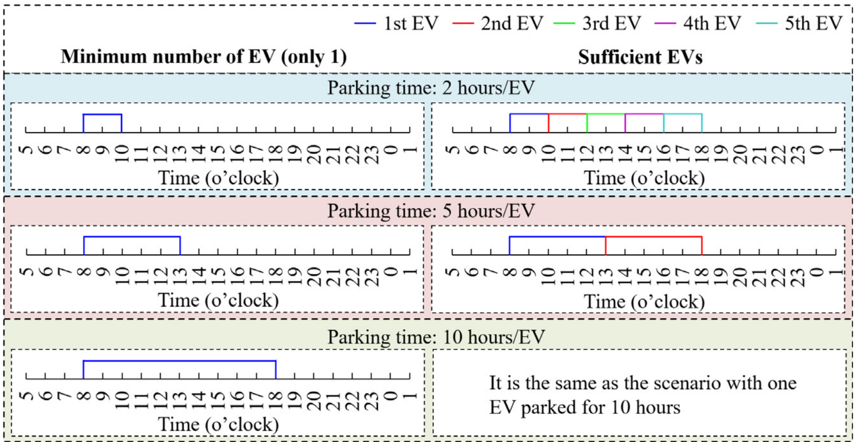

Fig. 5. EV availability/parking patterns.

3.4. EVESS energy recovery

Simulating the scenarios described above leads to the results shown in Fig. 6. Here the SoC of the EV's is shown against time. It is interesting to note that the frequent braking and acceleration events of the tram appear in the SoC graphs as a very small ripple on the vehicle SoC as energy is imported to the EV and then exported to aid the trams acceleration. These energy ripples are relatively small, and is governed by the relative impedance of the catenary and track to the substations/tramcar as well as the limited charge/discharge rate of the EV. Overall, the energy flow into the EV is greater than the flow out, leading to an overall charging of the EV over time.

The scenario of a single EV connected to the tram for 2, 5 and 10 h may be seen in Fig. 6(a), (b) & (c). Here the SoC of the EV shows that typically the vehicle becomes fully charged in 2 to 3 h. After this, the EV may still provide energy to the tram system to aid acceleration, but the vehicles ability to absorb regenerated energy is

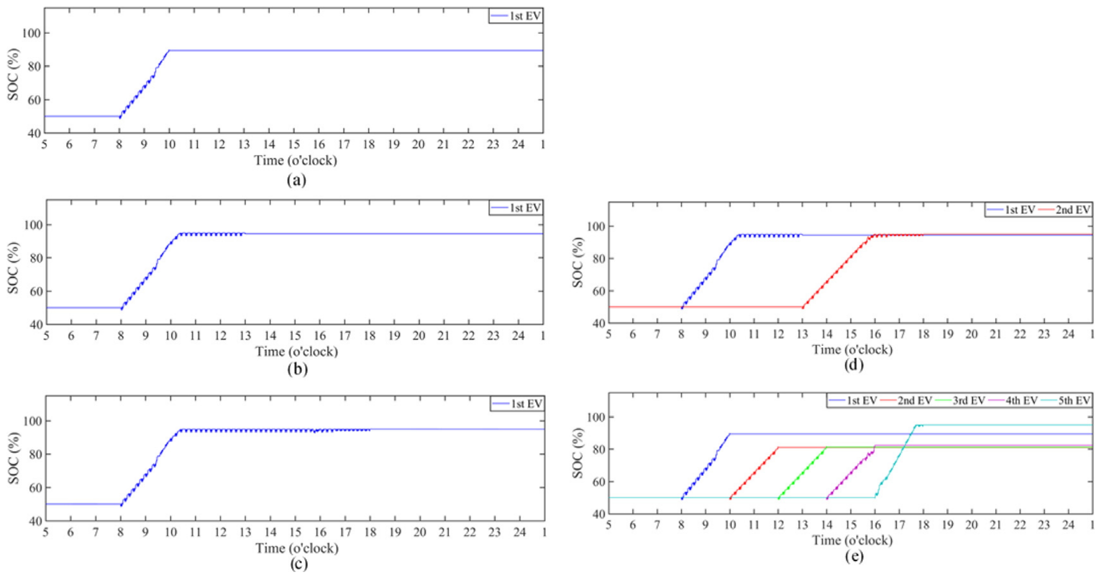

Fig. 6. EV availability/parking patterns.

severely limited, as the EV battery is fully charged. Therefore this is not an ideal operating scenario for the tram system, although the EV is charged as required.

Fig. 6(d) and (e) illustrate the SoC of individual EV batteries in the multiple EV's parked serially scenarios. It may be seen from the figures that when only 2 EV's are available, for a 5 h period per EV, the energy from the tram system is capable of full charging both EV's within their allotted parking slots. However, if 5 EV's are allocated to the system for a period of 2 h per EV, not every EV was able to be fully charged in their allotted parking slot. However, their SoC is still significantly improved over their SoC on arrival, after being charged from ∼50%b SoC to ∼80% SoC.

Fig. 7 shows the impact of the simulated scenarios on the energy supply from two substations on the track section between Carbrook and Nunnery Square. Here it may be seen that there is a significant drop in the substation energy supply through the use of EV's on the tram section, in addition to the drop in energy lost in the tram braking resistors. In the first 3 columns of Fig. 7, the results show that with only a single EV parked, the reduction of energy drawn from the substation during the operation day is directly proportional to the length of time the EV is parked on the system. Furthermore, as the EV battery is of a finite size, once the battery is charged, there is a limit to the amount of energy which can be stored in the battery, and hence removed from the system. In the right hand three scenarios, the impact of more than 1 EV can be seen. Here, as there is always a battery present on the system during the time of interest, the amount of energy saved at the substations is approximately the same, however the

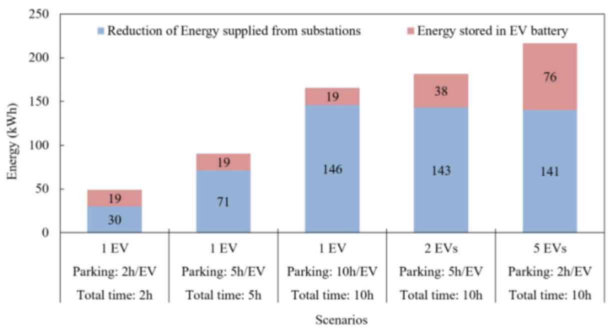

Fig. 7. Impact of EV's on the tram section substations.

amount of energy which can be removed from the system is proportional to the number of EV batteries available on the system during the period of interest.

3.5. Number of connection interfaces

The result presented above illustrates that the largest energy saving was achieved through having 5 EV's available to the system, with each EV battery being available to the system for 2 h per EV. In order to explore the impact of having more than one connection available for EV's to the tram system, a number of scenarios were simulated to explore the use of 1, 2 & 3 interfaces (chargers), each with either 1 or 5 EV 'customers' through the period of interest. This leads to a further six possible scenarios. The result of the energy savings brought about by these scenarios is shown in Fig. 8.

Here it may be seen that there is a correlation between the number of connections available to the EVs and the energy savings from the substations, irrespective of the number of EV's utilizing the connections (assuming the connections/chargers are always fully occupied). However, the number of EV's utilizing the connection devices/chargers correlate to the amount of energy stored in the EV batteries, as this directly influences the ESS capacity which is available to the system. It is interesting to note that when the EV capacity available to the system exceeds the amount of energy available from the tram system (∼82 kWh), the amount of energy removed from the system cannot increase further, despite the availability of EV's to charge.

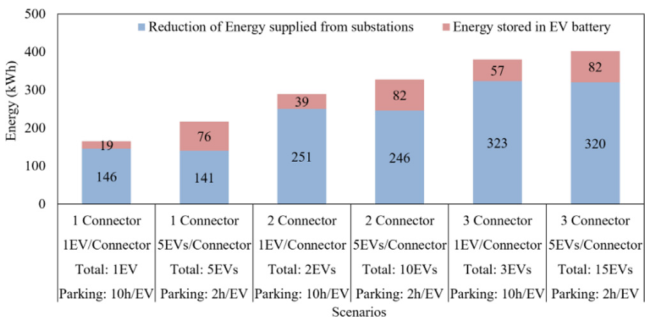

Fig. 8. Multiple connection scenarios.

4. Conclusion

This paper has examined the energy balance on an urban light rail/tram system, and has demonstrated that with the use of bi-directional EV chargers (interfaces), a significant amount of the energy lost in on-board dump resistors can be saved. In addition, the amount of energy drawn from substations can be reduced, leading to lower utility costs for the tram operator. This comes at the expense of installing bi-directional charging interfaces directly onto the tram network, but without the expense of installing static, lineside energy storage systems.

Declaration of competing interest

The authors declare no conflict of interest.

Data availability

The authors do not have permission to share data.

Acknowledgments

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References

[1] UK Paliament. Climate change act 2008. 2008, Available: http://www.legislation.gov.uk/ukpga/2008/27/pdfs/ukpga_20080027_en.pdf.
[2] BEIS. 2021 UK greenhouse gas emissions. London, UK: provisional figures; 2022.
[3] BEIS. 2019 UK greenhouse gas emissions. provisional figures, Department for Business, Energy & Industrial Strategy UK2020, Available https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/875485/2019_UK_greenhouse_gas_emissions_provisional_figures_statistical_release.pdf.
[4] European Commission. Electrification of the transport system: Studies and reports, directorate-general for research and innovation. 2017, Brussels, Belgium, Available: https://ec.europa.eu/newsroom/horizon2020/document.cfm?doc_id=46368.
[5] DfT. Transport statistics great britain 2020. Department for Transport, UK2020, Available https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/945829/tsgb-2020.pdf.
[6] Office of Rail and Road. Table 6105 - estimates of passenger and freight energy consumption and carbon dioxide equivalent (CO2e) emissions. 2020.
[7] Disney J, Rossiter W, Smith DJ. Nottingham express transit:The role of green innovation in the drive for sustainable mobility through improved public transport, vol.19, no. 1. 2018, p. 56–68.
[8] London-road-croydonorg. 2–8 London road, part 3: West croydon station in the 1900s. 2013, Available: https://london-road-croydon.org/history/0006-west-croydon-station-1900s.html.
[9] Srivastava JK, Singh VK, Singhal AK. Review on railway traction power supply system. J J Environ Sci Comput Sci Eng Technol 2013;2(4):1236–50.
[10] Stagecoach. Working near the supertram network. 2022, Available: https://www.stagecoachbus.com/supertram/working-near-supertram-network.
[11] Stanton P. Controlling docklands' traction. 2021, Available: https://www.railengineer.co.uk/controlling-docklands-traction/.
[12] Strathclyde Partnership for Transport. Celebrating 125 years of subway. 2022, Available: https://www.spt.co.uk/125/.
[13] EDINBURGH Tram (line one) bill - environmental statement - non-technical summary. 2006, Available: https://archive2021.parliament.scot/S2_Bills/Edinburgh%20Tram%20(Line%20One)%20Bill/line1-NTS.pdf.
[14] Transport for Greater Manchester. Working safely near metrolink. 2022, Available: https://tfgm.com/public-transport/tram/working-safely.
[15] Transport for West Midlands. Working safely next to West Midlands.
[16] UKtram. London tramlink. 2022, Available: https://uktram.org/systems/london-tramlink/.
[17] UKtram. Blackpool tramway. 2022, Available: https://uktram.org/systems/blackpool-tramway/.
[18] Gavin C. Seasonal variations in electricity demand. London: Department of Energy & Climate Change, UK2014, Available https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/295225/Seasonal_variations_in_electricity_demand.pdf.
[19] González-Gil A, Palacin R, Batty PJEc, management. Sustainable urban rail systems: Strategies and technologies for optimal management of regenerative braking energy,vol. 75. 2013, p. 374–88.
[20] González-Gil A, Palacin R, Batty P, Powell JP. A systems approach to reduce urban rail energy consumption. Energy Convers Manage 2014;80:509–24.
[21] Barrero R, Tackoen X, van Mierlo J. Stationary or onboard energy storage systems for energy consumption reduction in a metro network. Proc Inst Mech Eng Part F: J Rail Rapid Transit 2010;224(3):207–25.
[22] Xia H, Chen H, Yang Z, Lin F, Wang B. Optimal energy management, location and size for stationary energy storage system in a metro line based on genetic algorithm. Energies 2015;8(10):11618–40.
[23] Teymourfar R, Asaei B, Iman-Eini H, Nejati fard R. Stationary super-capacitor energy storage system to save regenerative braking energy in a metro line. Energy Convers Manage 2012;56:206–14.
[24] Ceraolo M, Lutzemberger G. Stationary and on-board storage systems to enhance energy and cost efficiency of tramways. J Power Sources 2014;264:128–39.
[25] Meishner F, Sauer DU. Wayside energy recovery systems in DC urban railway grids. ETransportation 2019;1.
[26] Lamedica R, Ruvio A, Palagi L, Mortelliti N. Optimal siting and sizing of wayside energy storage systems in a D.C. Railway line. Energies 2020;13(23).
[27] Szeląg A, Radu PV, Drazek Z, Karwowski K, Gold H, Zurkowski A. Analysis of wayside energy storage devices for DC heavy rail transport. In: MATEC web of conferences, Vol. 180. 2018.
[28] Radu PV, Lewandowski M, Szelag A. On-board and wayside energy storage devices applications in urban transport systems—Case study analysis for power applications. Energies 2020;13(8).
[29] Letendre S, Kempton W. The V2G concept: A new model for power? Public Util Fortnightly 2002;140:16–26.
[30] Kempton Willett, Tomic Jasna, Letendre Steven, Brooks Alec, Lipman Timothy. Vehicle-to-grid power battery hybrid and fuel cell vehicles as resources for distributed electric power in California. Davis: University of California, USA2001.
[31] Thompson AW. Economic implications of lithium ion battery degradation for vehicle-to-grid (V2X) services. J Power Sources 2018;396:691–709.
[32] Pearre NS, Ribberink H. Review of research on V2X technologies, strategies, and operations. Renew Sustain Energy Rev 2019;105:61–70.
[33] Thompson AW, Perez Y. Vehicle-to-everything (V2X) energy services, value streams, and regulatory policy implications. Energy Policy 2020;137.
[34] DfT and DVLA. Licensed ultra low emission vehicles by body type: united kingdom. UK: Department for Transport and Driver and Vehicle Licensing Agency; 2020.

[35] DfT and DVLA. Vehicles registered for the first time by body type. monthly: Great Britain and United Kingdom; 2020.
[36] The UK Government. Government takes historic step towards net-zero with end of sale of new petrol and diesel cars by 2030. 2020, Available: https://www.gov.uk/government/news/government-takes-historic-step-towards-net-zero-with-end-of-sale-of-new-petrol-and-diesel-cars-by-2030.
[37] Zhang T, Ballantyne EEF, Zhao R, Stone DA. Technical and economic feasibility of increasing tram system efficiency with EV batteries. Transp Res Part D: Transp Environ 2021;91.
[38] Zhang T, Zhao R, Ballantyne EEF, Stone DA. Increasing urban tram system efficiency, with battery storage and electric vehicle charging. Transp Res Part D: Transp Environ 2020;80.