Optimisation of Intermittent Electrification of Rail Transport for Near-Term Decarbonisation

Dr Will Midgley, Dr Bilal Abdurahman, Dr Chris Ward and Dr Tim Harrison
Loughborough University

Introduction

The UK rail network must be decarbonised to meet the UK Government's 2050 net zero commitment [1]. Electrifying incrementally/continuously has operational benefits but is expensive, costing around £2M-£3M per single-track kilometre [2]. Electrifying intermittently (i.e., leaving unelectrified gaps) might allow the UK to cut its greenhouse gas emissions faster and more cheaply in the short term than electrifying incrementally.

This work investigated the feasibility of intermittent electrification and developed a method for finding the optimal intermittent electrification strategy for cutting emissions the fastest.

Modelling

An initial model developed by the team presented a high-fidelity model of a 5-car electric-diesel bi-mode rail vehicle that allowed detailed modelling of the CO2 emissions of these trains when meeting a given timetable [3]. This project built on that model by improving the speed control and the modelling of individual components such as the electric motors.

A battery pack based on a high-charge/discharge lithium-titanite oxide (LTO) battery module has been modelled and installed on the train. This was used to investigate the battery-electric hybrid train's traction performance, and the feasibility and energy benefits of replacing diesel engines with batteries on trains running on intermittently electrified tracks. Optimal battery sizes were also identified for given percentages of optimal intermittent electrification.

The optimal electrification strategy devised in [4] was improved to include the energy consumption for both directions of travel, as opposed to a single travel direction. The Newbury-Plymouth route was divided into 50 5.6-km sections and the maximum energy consumption for each direction of travel was selected as the energy footprint for each section. The optimal intermittent electrification method was then found using the strategy in [4].

Results

Optimal intermittent electrification can reduce operational CO2 emissions by up to 54% when compared to the same length of continuous electrification [4]. This happens at 50% of route electrification as shown in Figure 1. At full electrification, both intermittent and continuous electrification provide the same operational CO2 saving.

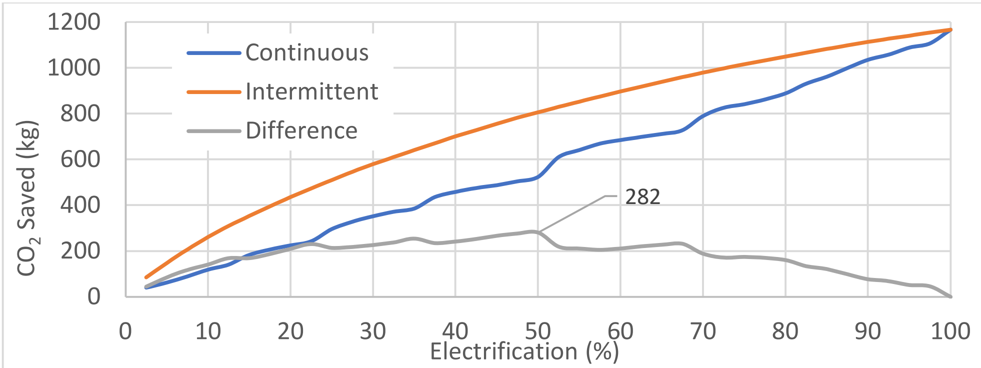

Figure 1: CO2 saved from discontinuous (intermittent) and continuous electrification [4]

Replacing a diesel engine with a battery can allow energy savings as the battery-electric train can recover energy during braking through regenerative braking. Of the 2.5MWh required to move a fully laden 5-car Class 80x train with the weight diesel engines from Plymouth to Newbury, approximately 1.2MWh of this energy is available for recuperation through regenerative braking.

Modelling was used to determine the required battery capacity for the train at different extents of intermittent electrification (see Figure 2), where the battery was sized to ensure its state of charge (SOC) never dropped below 20%, and an additional 25% capacity was added to account for battery wear over its lifetime. (This, taken with the high power requirements, explains the higher-than-expected battery capacities for low amounts of electrification.) The amount of energy saved (recuperated) by the battery is also included in Figure 2.

Also included in Figure 2 is the results of a ‘common sense manual approach’ to optimization that consists of longer 10-km stretches of electrification centred on stations and the hilly section connecting Totnes and Ivybridge (the triangle and square at 36% electrification). This produced a much lower battery size (around half the size) as these sections include much of the high power demand for the route. In contrast, the discretised method is constrained to using 5.6-km sections which can result in different choices for electrification.

At 36% of optimal electrification, the battery would undergo an average of 5475 cycles per year at 5 trips per day (approximately 15 cycles per day), a standard LTO datasheet [5] suggests that the batteries would be able to operate for about 1.1 year (at 550C) before their capacity is reduced to 80%. At this point they may need to be replaced and the old batteries could be used for lineside storage or recycled.

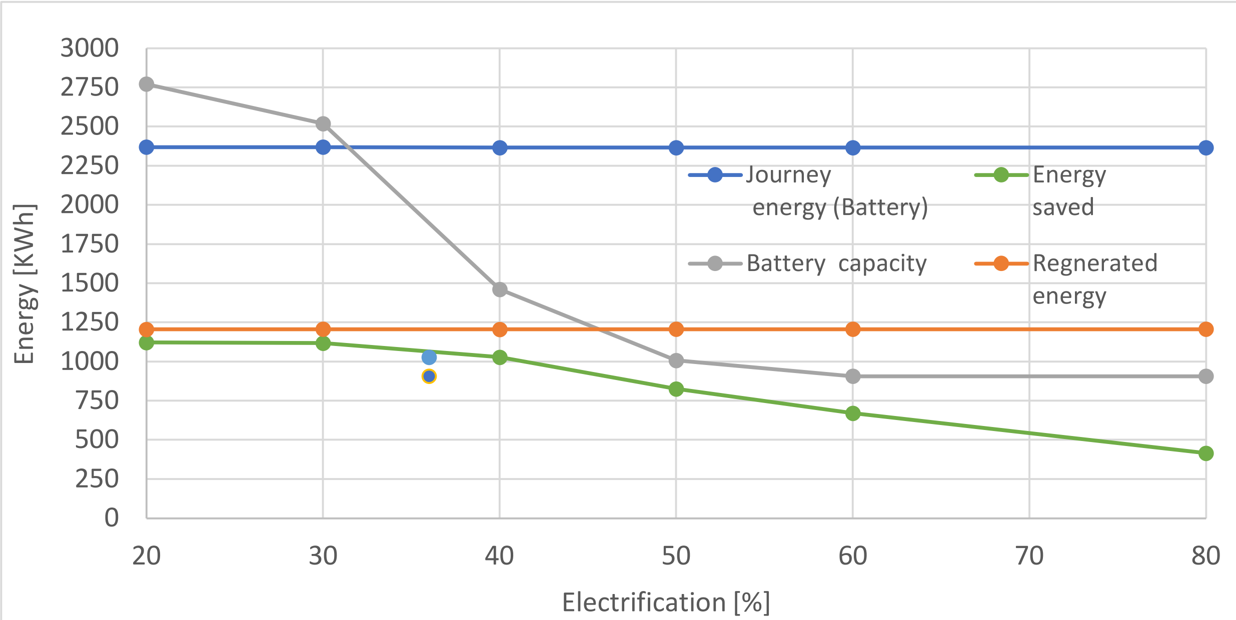

Figure 2: Effect of intermittent electrification on battery size and energy saved

Conclusion

This study has shown that intermittent electrification would provide the fastest means of decarbonising the UK railway, saving up to 50% more CO2 than continuous electrification. It has also shown that battery infill for electrified sections is feasible, to allow complete decarbonisation of the rail network whilst electrification progresses.

However, practical considerations for intermittent electrification and battery infill remain. These include the raising and lowering of pantographs at speed, the connection of two adjacent electrified sections and end-of-use considerations for traction batteries.

References

[1] UK Government, The Climate Change Act 2008 (2050 Target Amendment) Order 2019, vol. 2, no. 6. Queen’s Printer of Acts of Parliament, 2019, pp. 1–2.

[2] Network Rail, “Traction Decarbonisation Network Strategy,” 2020. [Online]. Available: https://www.networkrail.co.uk/wp-content/uploads/2020/09/Traction-Decarbonisation-Network-Strategy-Executive-Summary.pdf.

[3] T. J. Harrison, W. J. B. Midgley, R. M. Goodall, and C. P. Ward, “Development and control of a rail vehicle model to reduce energy consumption and carbon dioxide emissions,” Proc. Inst. Mech. Eng. Part F J. Rail Rapid Transit, vol. Online Fir, Feb. 2021 doi: 10.1177/0954409721993632.

[4] B. M. Abdurahman, T. Harrison, C. P. Ward, and W. J. B. Midgley, “An investigation into intermittent electrification strategies and an analysis of resulting CO2 emissions using a high-fidelity train model,” Railw. Eng. Sci., Jul. 2021 doi: 10.1007/s40534-021-00248-9.

[5] Altair Nanotechnologies: 24V 70Ah battery module, 2016. Available at: https://altairnano.com/wp-content/uploads/2017/06/Copy-of-24V-70Ah-MODULE-DATA-SHEET-MKT-500-3341421-1-R1-1.pdf (Accessed: 16/09/2021).