Executive Summary

The world has committed to move towards a low-carbon economy[1]. The European Union (EU) has set a long-term goal of reducing greenhouse gas (GHG) emissions by 80-95% by 2050 with respect to the levels of 1990[2]. The primary measure to achieve that is through electrifying more the transport sector by encouraging the electrification of railway lines along with the adoption of road electric vehicles (EVs) since the transportation sector is the major emitter of GHG and the level of release of harmful gases nearly unchanged at level of 1990s[3]. At the same time, there is a need to ensure that the transport is safe, and its industry remains competitive on the global market. Fuel hydrogen cells (FHC) have been presented as great candidate to replace other powertrain technologies in rail transportation. They offer reduced or zero emission options for rail transportation in various applications currently powered with diesel engines or liquefied natural gas (LNG) powered trains[4]. Moreover, they are better alternatives to power the trains in railway network instead of development of a dedicated electrical grid to supply the railway network and this requires upgrading of the distribution electrical network and involves more costs. Nevertheless, a hydrogen infrastructure to support refuelling at the scale required for railway use has been neglected. There is a critical issue which potentially could delay the full-scale introduction which is the availability of high-quality bulk hydrogen for rail vehicle refuelling.

On the other hand, the traction demands of the railway network are characterized by their rapid variations depending on the trains' operational conditions and timetables. Besides, even though FHC are good energy sources to provide reliable power at a steady rate, they cannot respond appropriately to the tractions' fast load transients due to their slow internal electrochemical and thermodynamic responses. Alternatively, they can be integrated with energy storage device with fast dynamics such as Li-ion battery cells (LiBC) to form a hybrid power source for traction systems.

Accordingly, this project proposes a development of a new smart integrated power source of FHC and LiBC to supply dual three-phase machines for driving the trains in railway networks. Moreover, it will present novel and transformative approaches towards establish a Hydrogen (H_2) refuelling system for such railways' vehicles which are supplied by the new proposed integrated power source of FHC and LiBC. Eventually, an optimization analysis has been carried out to reduce the overall hydrogen consumption with the same journey time spent using Particle Swarm Optimisation approach.

The main activities for the project are provided as follows:

- Requirements elicitation

Systems engineering is used to develop a process for requirements capture given the university of Birmingham's excellent industrial links with the railway and hydrogen sectors. Accordingly, a number of railway case studies are investigated, and the best railway line is nominated through selection criteria for the implementation of the new smart drive traction system.

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[1] The Paris Agreement, 2020 United Nations Framework Convention on Climate Change, [Online]. Available: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

[2] Regulation (EC) No 1099/2008 of the European Parliament and of the Council of 22 October 2008 on energy statistics, [Online]. Available: https://ec.europa.eu/eurostat/web/energy/legislation

[3] Low carbon transport, 2019 Energy UK, [Online]. Available: https://www.energy-uk.org.uk/our-work/new-energy-services-and-heat/low-carbon-transport.html

[4] Y. Ruf, et al. "Study on the use of fuel cells and hydrogen in the railway environment." Research report by Shift2Rail Joint Undertaking and Fuel Cells and Hydrogen Joint Undertaking, 2019.

- HIL development and validation for the new drive traction system

Hardware-in-the loop (HIL) procedure is implemented for the new drive traction system where the models for the proposed new drive system are developed in the Typhoon HIL404 equipment.

- Concept design for H_2 refuelling station and operation optimization

The concept design for hydrogen (H_2) refuelling station will be a desktop study, where the outputs are provided to articulate the overall design of a H_2 refuelling system. Furthermore, an operation optimization analysis is presented to reduce the overall hydrogen consumption with the same journey time spent using Particle Swarm Optimisation approach.

- Engagement and dissemination

Engagement activities have been undertaken with the Network-H2 for the hydrogen transportation through a number webinar and workshops. Moreover, a new journal paper, based on the research outcomes, will be submitted to Hydrogen Fuelled Transportation, Forthcoming Special Issues, International Journal of Hydrogen Energy.

Accordingly, the project key findings are demonstrated as follows:

With respect to the new developed hybrid traction system, the removal of DC/DC converter and integration of dual three phases permanent magnet synchronous motor (DTPMSM) is added up the control complexity for independently fed power supply. Nevertheless, it includes more advantages as the new configuration is going to be more compact and promising to implement catenary free FHC and LiBC powered hybrid trains compare to the traditional ones. Moreover, the torque density of the traction motor is higher, and size of the power converter unit reduces by the involvement of the new traction scheme. As a next step, T-type neutral point clamped (NPC) converter unit would be considered to replace the voltage source inverters. As a result, the feature of fault tolerant of the machine is achieved. This enables to disconnect the faulted part of the traction system which might be the DC power supply or faulted winding by using converter switches.

On the other hand, for the H_2 refuelling station, based on the selection criteria of land area, necessary empty coaching stock moves, and other rolling stock requirements, the anticipated location for the H_2 refuelling station is chosen for a certain rail route under study (the St. Erth to the St. Ives branch). Furthermore, the production of the hydrogen on site is also the desirable approach, ideally using a containerised solution. Besides, the decant method of refuelling is more appropriate for this context and only one train will need to use the refueller; thus low pressure “buffer” storage is considered unnecessary. For future work, number of processes have to be carried out in order to determine the exact arrangements necessary for designing the H_2 refuelling station. Processes such as rolling stock design, specifically the positions and type of connections for hydrogen fuelling and toilet waste removal, as well as a study of each of the components of the system, and selection of the optimal candidates.

Lastly for the implemented optimization case study, the hydrogen consumption has obviously reduced after applying the optimal speed profile. With the reduction of hydrogen requirement (around 10% after the optimization process), the train can install fewer hydrogen tanks compared with the benchmark design. Especially for the low energy density like hydrogen, the volume saving would be more obvious than other fuel trains, such as diesel trains. Therefore, the saved space can be designed for other functional facilities, such as passenger seats and luggage racks.