SIF Project Registration

Date of Submission

Mar 2022

Project Reference Number

10025479

Project Registration

Project Title

Resilient and Flexible Multi-Energy Hub Networks for Integrated Green Mobility

Project Reference Number

10025479

Project Licensee(s)

SP Energy Networks Transmission

Project Start

March 2022

Project Duration

2 Months

Nominated Project Contact(s)

Michael Eves

Project Budget

£151,938.00

Project Summary

Rail is the single largest electricity user in the UK, consuming 4 TWh electricity pa (1.2% of UK total), with projected 3TWh electricity demand increase along with railway decarbonisation, requiring £18bn to £26bn investment.

This project will investigate for the first time the feasibility of developing resilient and flexible railway multi-energy hubs around 2500 railway stations and connecting these hubs to form a hub network, with the following objectives:

1. "Efficiency and flexibility improvement" – Maximise opportunities for zero-emission transport modes to deliver smarter energy systems at these stations through coordinated energy supply, power to trains, electric vehicles and buses, non-traction power and energy demand, V2T, V2S, and V2G.

2. "Emission reduction" – Integrate local renewable energy production and energy storage.

3. "Power security" - Strengthen traction power supply along 10,000 miles railway routes by networking the hubs to support on-going railway electrification and decarbonisation and to meet the growth of railway services.

4. "Power grid support" – Improve power grid resilience and flexibility by providing services where possible, such as demand side response, frequency and voltage support.

The discovery phase will select a small sample of suitable railway stations to investigate the feasibility of multi-energy hubs design, addressing the following issues:

1. Energy efficiency and system flexibility improvement potentials of energy hubs.

2. Uncertainties and operational risks.

3. Suitable power electronics architecture to meet AC and DC power demand and exchange at different voltage levels.

4. Operation and control challenges to coordinate energy conversations and exchanges.

5. Business models.

This project will deliver:

- Energy efficiency analysis tools to support Network Rail maximise efficiency improvement potentials around 2500 railway stations.

- Stakeholder engagement to convert sample railway stations into energy hubs in alpha and beta phases to support roll-out of the energy hub technology in achieving decarbonisation of 60% unelectrified routes with reliable traction power supply by 2050.

This project is led by SP Transmission plc and SP Distribution plc with three partners of substantial expertise in energy innovation, railway electrification and rail economics - Network Rail (infrastructure provider): railway expertise and data; University of Leeds (academic user): railway power electronics and railway economics; Ricardo (3rd party innovator): electricity supply decarbonisation and novel power electronic devices connecting traction network to distribution network.

This project addresses the security challenges facing both railways and power sectors when the future energy system almost entirely runs on low carbon energy sources.

Third Party Collaborators

Ricardo

University of Leeds

Nominated Contact Email Address(es)

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Problem Being Solved

- Transportation generates the largest share of GHG emissions in UK (34% in 2019), 60% British rail has not been electrified, diesel trains produce 1.6 MtCO2e pa.

- Rail decarbonisation requires extensive network upgrades which are often complex and extremely costly, e.g. rail electrification costs £1 million - £2.5 million per km.

- Railway traction power supply lines span wide areas, with feed stations connected to different electric grids (strong grids coexisting with weaker ones), power grids faults may cascade down to the traction power supply systems, causing trains to stall on track and cancellation of service routes, resulting in significant economic losses and public dissatisfaction.

- Integration of intermittent renewable generations to power grids at all voltage levels imposes significant challenges to grid operations, further complicating a reliable power supply to the railway.

The opportunities:

- Railway stations in populous, urban areas are interchange points between different mobility modes travelling to/from the station and rail. Energy exchanges at these station locations are huge and can be made more efficient through novel power electronics solutions and whole system coordination.

- Significant V2X potentials (vehicle-to-grid V2G, vehicle-to-train V2T, vehicle-to- station V2S). Of the 388m rail passenger journeys made in 2020-21, if 1% travel by EV to the station, the aggregated battery storage is in the range of ~200GWh. While over 300 category C or above stations are big energy consumers, e.g. a high-speed railway station consumes 117-470kWh/(m2.a) for non-traction purposes e.g. lighting, HVAC.

- Railway traction uses over 4 TWh of electricity p.a., if all routes are electrified, this adds 3TWh. Taking 1% of the energy consumptions (for both traction and non-traction purposes) at all station locations results in an aggregated energy saving and/or shiftable capacity in the GWh per day range, hence offering significant flexibility capacity for power grid operation to accommodate

more renewable generations.

By converting train stations into a first of its kind multi-energy hub network, the project provides the following customer benefits:

- Energy/cost savings (by avoiding electrification works)
- Significantly reduced carbon emissions (by removing diesel generation)
- Reduced traction power supply faults, hence reduced passenger delays, and increased satisfaction and use of train travel, therefore increased revenue
- Enhanced power grid operation (via demand side response, V2G, and grid service provisions)
- Improving the stability of critical infrastructure for both railways and power sectors when the future energy system almost entirely runs on low carbon source

Project Approaches And Desired Outcomes

The Big Idea

Leveraging substantive expertise from the consortium, this project proposes for the first time to develop multi-energy hubs around 2500 railway stations across over 10,000 miles of UK rail to improve energy efficiency with greater flexibility to support power grid operation, networking these hubs to enhance the overall traction power supply security and resilience, and the integration of renewable generation.

Key technologies for energy hubs include:

1. AI assisted Digital twin technology, as an enabler for optimal energy management and optimal design/retrofit of energy conversion components and energy storage devices to improve energy efficiency and extend system flexibility.

2. Novel power electronics-based energy hub technology to meet AC and DC power demands of different voltage levels, such as traction and non-traction electricity supply, recovering train braking energy, V2T and V2G, and integration of local renewable production.

3. Advanced control framework to achieve real-time system performance in delivering energy efficiency in railway stations and providing market signal driven control actions to allocate the system required flexibility from both traction and non-traction loads to support power grid operations, e.g. balancing and congestion relief, grid stability, and black-start.

4. Optimal planning and operational framework of networked hubs and feed stations across different regions to enhance the traction power supply resilience and integration of renewable generations at local level, including novel protection schemes to enhance system resilience and minimise downtime in case of partial/total transmission system blackouts, and support bottom-up low voltage black-start functionalities.

Novel power-electronics solutions such static frequency converters (SFCs) are recognized as the future feed-stations bringing significant flexibility and energy efficiency to the traction power supply. It has been used on European railways and a few other countries. Network Rail has started to construct SFC feed stations on East Coast main line. Two SFC stations at Hambleton and Marshall Meadow are expected to reduce costs by 60% compared with the cost of providing a new high voltage grid connection for the site.

The energy hub proposal leverages this latest development and is a step change to maximise the full potentials of novel power electronics solutions and digital twin technologies to support railway decarbonisation.

This discovery phase uses selected stations in Scotland as case studies to investigate the feasibility of multi-energy hubs design via whole systems approach. New IP will be created, documented and disseminated under the default IP arrangements in the SIF governance.

Innovation Justification

The consortium team has a strong track record of leading/participating in multidisciplinary research projects on transport decarbonisation, smart grid and microgrid, is currently undertaking/has just completed over £10m of research and innovation in complementary areas. In EPSRC project 'Intelligent grid interfaced vehicle eco-charging (iGIVE)', an intelligent charging system was developed to support V2G and G2V while ensuring safe and reliable operation of vehicle batteries. In EPSRC 'TransEnergy - road to rail energy exchange' a techno-economic supply chain analysis of energy storage technologies was conducted for application in UK rail and road transport. In EPSRC 'Creating resilient sustainable microgrids through hybrid renewable energy systems', a novel microgrid planning tool was developed.

Our research confirms that transportation decarbonisation requires significant investment, while a future power system almost entirely running on low carbon energy sources need significant levels of full-chain flexibility to maintain energy security to integrate high level renewable power.

The railway research and industry communities in the UK, EU and worldwide have vibrantly explored the opportunities in the past few years to introduce renewable energy sources to the traction power systems and extend the smart grid and microgrid concepts to railway systems, such as integrating renewable energy sources, energy storage, road energy supply, and recovery of braking energy of the trains.

However, most railway microgrid concepts primarily focus on electric power exchanges along the traction power systems, little has been done to explore the energy efficiency and flexibility potentials of huge energy exchanges at urban populous railway stations which serve millions of passengers annually in the UK's busiest stations.

Conversely, redeveloping railway stations and their surroundings is high on the agenda of UK/European cities, largely under 'transit-oriented development (TOD)', and the coordinated management of the energy mix in these stations and surrounding areas for both traction and non-traction purpose has never been properly researched. This proposal for the first time underpins the stations as energy and transport nexuses and aims to build multi-energy hubs, the first of their kind, around these stations and connect them across over 10,000 miles of UK rail, connecting cities/communities across the country to support green mobility and a future low carbon power grid, running almost entirely on renewable sources. This would not limit the energy benefits to a specific city/region, but across the whole of the UK, with this innovative concept transferable to other areas (London Underground) and countries.

Project Plans And Milestones

Project Plan And Milestones

The project team will follow PRINCE2 principles and ISO9001 standards to adopt agile and flexible approach for project progress monitoring, tasks delivery, cost management and risk mitigation. A risk register with mitigation actions will be maintained throughout. Five coherent WPs are designed. SP Transmission plc will manage the project and lead WP0, the University of Leeds will lead WP1-4.

WP0) Pre-project preparation for WP1-4

- Form project steering group from key stakeholders: SP Transmission plc, SP Distribution plc, Network Rail, etc;
- Agree selected stations for case studies.
- Gather, format and review data for selected stations. WP1) 'Business-as-usual' analysis (4 weeks)
- Analysing historic data from WP0 to evaluate the traction/non-traction energy consumptions/efficiency.
- Milestone 1: Report on energy consumption/efficiency mapping of selected railway stations with qualitative and quantitative tools.

WP2) Energy hub potentials assessment (4 weeks)

- Projection of energy efficiency and system flexibility improvement potentials with/without the dedicated energy hubs based on the analysis results from WP1.
- Investigate uncertainties created by variable local renewable sources coupled with variable loads to assess the operational risks.
- Milestone 2: Report on potential benefits of energy hubs and operational risks.

WP3) Investigation of suitable energy architecture for energy hubs (6 weeks)

- With inputs from WP0-2, design tailored hub conceptual framework to meet AC and DC power exchange demands at different voltage levels, and to coordinate energy conversion and energy flow among different energy forms, such as traction power supply, EV charging and Vehicle-to-Train, power-to-heat, etc.
- Builds on Leeds' SFC and modular multi-level converters (MMC) expertise for railway feeder stations.
- Investigate novel multi-layer MMC structure and associated control/operation schemes to meet power exchange demands.
- Investigate digital twin technology based on Leeds' multi-energy simulation platform for coordinated management of energy mix.
- Milestone 3: technical report on novel all power electronics based multi-layer MMC structure and digital twin technology.

WP4) Cost benefit analysis (6 weeks)

- With inputs from WP0-3, investigate social economic feasibility of multi-energy hubs around identified stations and regulatory barriers for market access of the aggregated flexibility service from energy hubs.
- Milestone 4: Cost analysis report on energy hubs and regulatory policy recommendations. The project will not be a success without its partners – University of Leeds, SP Transmission plc, SP Distribution plc, Ricardo, and Network Rail – providing insight, innovation and critical function of in-kind contributions, whether this is their time, station access and data sets.

Route To Market

Phased Route to UK and International Markets

The Discovery Phase will select a small sample of suitable railway stations to investigate technical and commercial feasibility of multi-energy hubs design. On completion of the Discovery Phase, the following steps will be taken to maximise utilisation:

- Design a technical solution for construction of the energy hub for a railway station in Scotland to confirm the validity of energy hubs

(Design Phase, 6 months);

- Upon successful completion of Design Phase, the Demonstration Phase implements the solution at the identified stations, with a view to rolling out to other stations across Scottish Rail post Demonstration Phase;

- In collaboration with Network Rail and partners, integration of the energy hubs into HS2, East Coast Mainline, Northern Powerhouse Rail and TRU programmes, to look at securing additional funding rollout across England;

- Explore the avenue of securing Europe's Rail (EU's Shift2Rail successor) funding to apply to stations across Europe;

- As a commercial venture, work with project partners Network Rail and Ricardo, potential commercial partners such as GE, Siemens, ABB, Schneider Electric and Fujitsu, who have both UK and global involvement in rail technology (and alternative industries to rail), to look at the design/provision/creation of hardware/software that would add value to the project, particularly around power asset monitoring; and

- Linked to the above, potentially creating a unique University of Leeds spin off company to further develop and commercialise the project.

Transition to Business as Usual

Network Rail is the largest electricity consumer and a large fossil fuel consumer in the UK, consuming over 4 TWh electricity and 469 million litres diesel in 2019-20 alone. UK Government has planned to phase out diesel-only trains by 2040, while the Rail Decarbonisation Action Plan is a top priority for Scotland's Railway. The energy hubs have cost saving potential in the range of billions and contribute to the overall energy system flexibility. The SIF Alpha and Beta stages could be used to accelerate these solutions towards Business as Usual in the UK and international markets.

Non-licensee project partner investment

The energy hubs have cost saving potential in the range of billions for Network Rail and contribute to the overall energy system flexibility. In the discovery phase, Network Rail will provide data and expertise before and during the project period, totalling £12,000.

Costs

Total Project Costs

151938

SIF Funding

118780

This project has been approved by a senior member of staff

☑ Yes