UNIVERSITY OF LEEDS

Grid Support from Electrified Rail Transportation

Prof Kang Li

School of Electronic and Electrical Engineering

University of Leeds

k.li1@leeds.ac.uk

Outline

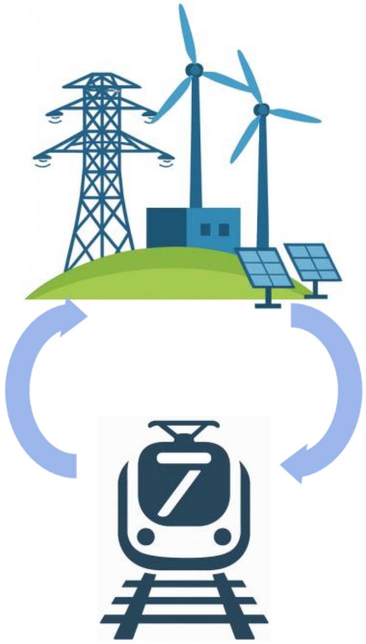
UNIVERSITY OF LEEDS

- **Introduction**
- Railway energy hubs
- Congestion and curtailment reduction
- Ancillary service
- Inertia support

Introduction

UNIVERSITY OF LEEDS

Potentials of Electrified Railway Networks to Support Power Grid



GB railway network

- ❖ **20,000** miles of track, 39% electrified, 2040/2035
- ❖ Coupling with HV power grid

GB Power network

- ❖ **5,340 miles** transmission line

Potential Support:

- ❖ Inertia support
- ❖ Reduce curtailment and congestion
- ❖ Flexibility and ancillary services
- ❖ Improve energy efficiency

Introduction

UNIVERSITY OF LEEDS

- Introduction
- **Railway energy hubs**
- Congestion and curtailment reduction
- Ancillary service
- Inertia support

Railway energy hubs

UNIVERSITY OF LEEDS

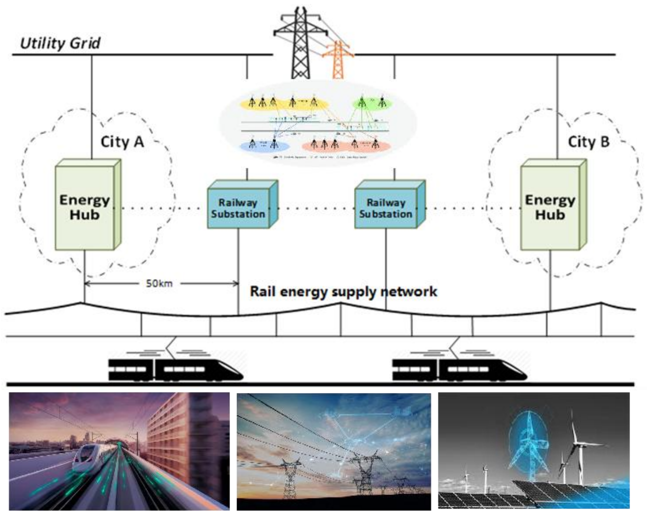
Challenges in Railway Electrification

- **Network Rail** is the largest electricity consumer in the UK, consuming over ~4TWh annually (=1.5 million homes)
- "**Inflexible**" **Power Demand:** driven by rail timetables
- Only **39%** of rail routes are currently electrified
- **Railway Decarbonization:** entails **~**3TWh increase in demand
- **High Investment Cost:** £1-2.5m per single track kilometer

Railway energy hubs

UNIVERSITY OF LEEDS

Concept and Functionality of Energy Hubs



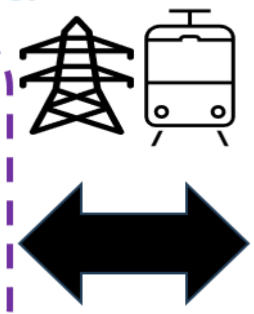
Key technology:

- DC/AC microgrids
- Hierarchical Control
- Digital twin

Potential Services from Energy Hubs:

Services to the electricity grid

- Demand flexibility services (inc. mitigation of wind power curtailment)
- Grid power balancing (frequency regulation)



Services to the railway

- Traction voltage regulation for electrified routes
- Battery train charging for non-electrified routes
- Backup power supply for rail depots
- Electricity cost saving (solar generation and low-tariff purchase)

Outline

UNIVERSITY OF LEEDS

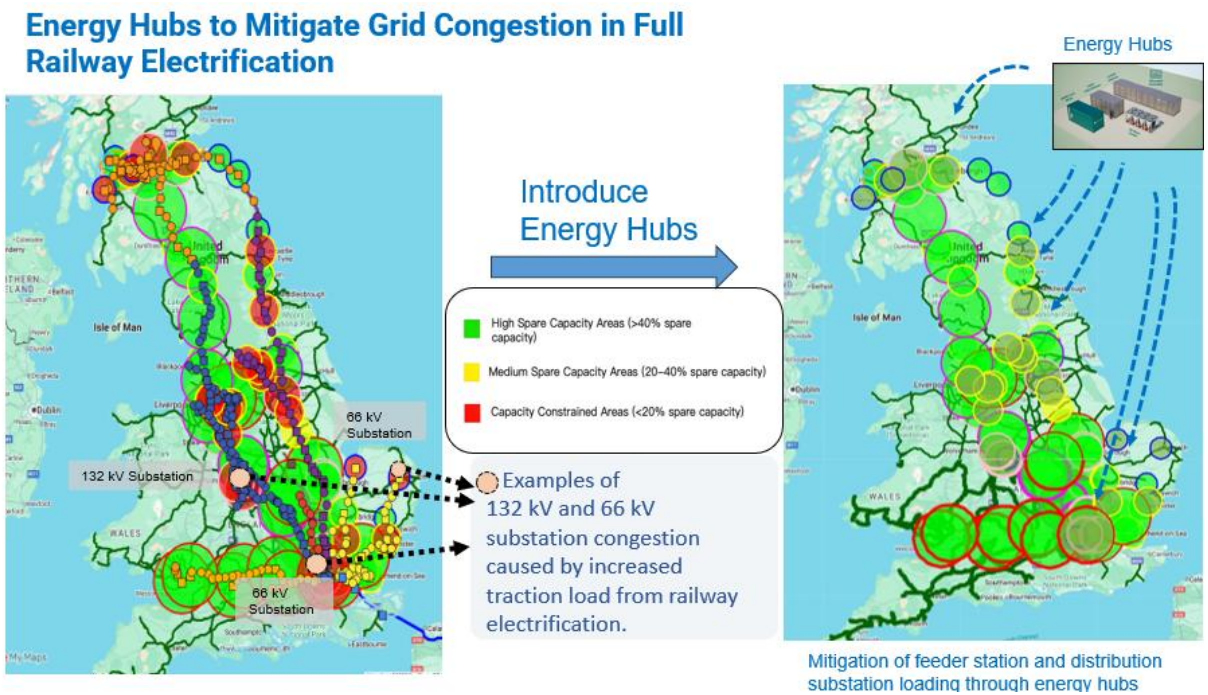
- Introduction
- Railway energy hubs
- **Congestion and curtailment reduction**
- Ancillary service
- Inertia support

Congestion and curtailment reduction

UNIVERSITY OF LEEDS

Wind Curtailment:

- Wind curtailment payments are given to operators for switching off turbines, typically when high winds and a high concentration of wind farms and the excessive energy can not be transported to where it is needed.
- The cost is added to domestic electricity bills, heaping more burdens on households.



Outline

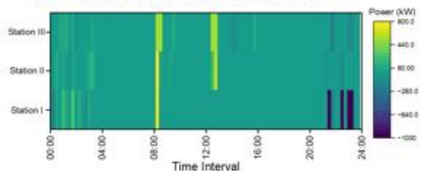
UNIVERSITY OF LEEDS

- Introduction
- Railway energy hubs
- Congestion and curtailment reduction
- **Ancillary service**
- Inertia support

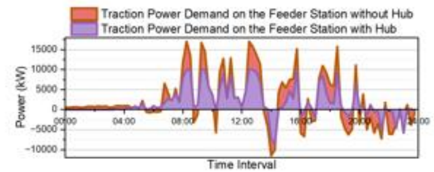
Ancillary service

UNIVERSITY OF LEEDS

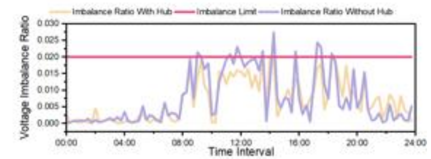
✓ Mutual Support Between Railway Systems and Local Distribution Networks



✓ Peak Shaving and Valley Filling of Traction Load Demand



✓ Three-Phase Voltage Imbalance Mitigation



Dynamic service delivery requirements:

Service specification	Description	DC	DM	DR
Initiation time	The maximum time between a change in frequency and change in the delivery of response	0.5s	0.5s	2s
Max time to full delivery	The maximum time between frequency deviation occurring and delivery of the saturation quantity	1s	1s	10s
Delivery duration	Time that an energy limited provider must be capable of sustained delivery	15 minutes	30 minutes	60 minutes

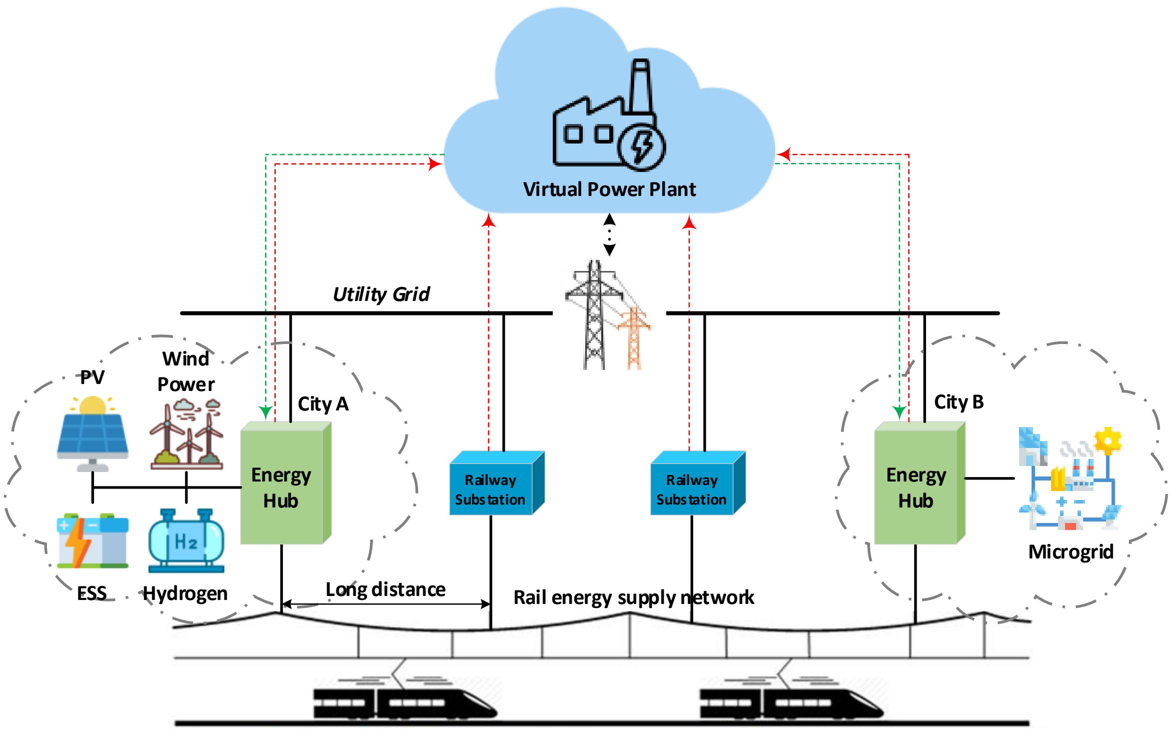
During the evening, when there is no traction load demand, the energy hub provides frequency response services to the power grid.

Ancillary service

UNIVERSITY OF LEEDS

Networked Energy Hubs

- Aggregates multiple hubs (traction, storage, renewables)
- Provides **system-level ancillary services**
  - Frequency regulation
  - Virtual inertia support
  - Peak shaving & valley filling
- Enhances **integration with power grid & markets**



👉 **Core idea:** Coordinated control for networked-energy- hubs-based VPP

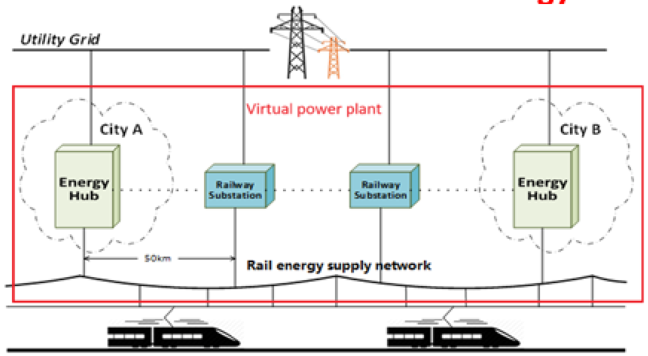
Outline

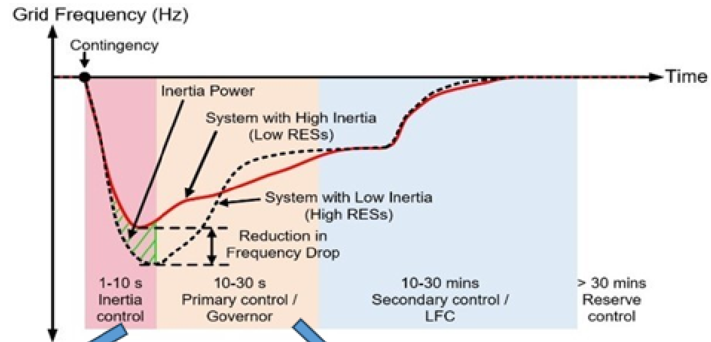
UNIVERSITY OF LEEDS

- Introduction
- Railway energy hubs
- Congestion and curtailment reduction
- Ancillary service
- **Inertia support**

Inertia support

Coupling railway network with HV transmission network via networked energy hubs for frequency regulation





Victim → **Potential Solution**

- Massive, distributed kinetic energy store
- Regenerative braking
- Rapid, short term power boost

Inertia Support (IS)

- Purpose: Instantaneous power injection to slow the Rate-of-Change-of-Frequency (RoCoF).
- Response: **< 100 ms**
- Power: Up to **~550 MW**
- Limited by converter current rating.

Frequency Support

- Purpose: Sustained power injection to arrest frequency fall and aid recovery.
- Duration: **60 seconds**
- Power: Up to **~400 MW** (with a 90% speed deviation)
- Limited by train kinetic energy and allowable speed drop.

C. Henderson, A. Egea-Alvarez, J. Rull-Duran, M. Nedd, P. N. Papadopoulos and L. Xu, "Inertia and Frequency Support From Britain's AC Powered Trains," in *IEEE Transactions on Sustainable Energy*, vol. 14, no. 2, pp. 1259-1268, April 2023, doi: 10.1109/TSTE.2022.3221192.

Summary

UNIVERSITY OF LEEDS

- Electrified railway transport supports power grid operation
- Railway energy hubs offer services to both railway and power grids
- Day-time grid support: running trains provides inertia support
- Night-time: energy hubs provide ancillary and flexibility services

Thank you!

Acknowledgement

SP ENERGY NETWORKS

UKRI Engineering and Physical Sciences Research Council

ofgem

UKRI Innovate UK

NetworkRail

nationalgrid

GE VERNOVA

RICARDO