Developments in Traction Systems

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What is new in Traction?

- Physics of traction – no change there!
- Traction drives – lots of legacy stuff around
- Railway energy consumption – lots of concern about how to save energy
- Some new concepts for future traction
- Summary

Overview of energy and power

- Linear motion of a railway vehicle can be described using standard equations of motion derived from Newton’s Laws
- Force = Mass x Acceleration (Newton)
- Work Done = Force x distance (Joule)
- Power = Work Done / time (Watt)

What is a Newton, a Joule or a Watt?

If we lift the apple through 1 metre in 1 second then the power is:
P=WD / time = 1 Watt

If we lift the apple up through 1 metre then the work done will be:
WD=F x d = 1 Newton x 1 Metre = 1 Joule

F=M x a = 0.1 kg x 10 m/s^2= 1 Newton

So...

- A kettle boiling water is equivalent to 3,000 apples being lifted vertically at a speed of 1 m/s
- A Eurostar train at full power is equivalent to 12 million apples being lifted vertically as a speed of 1 m/s

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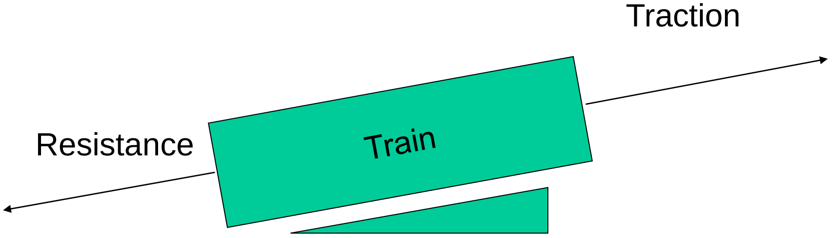
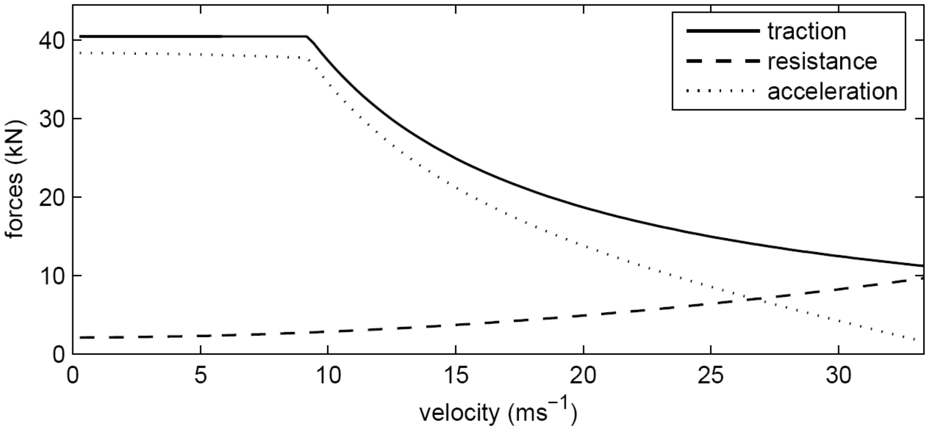
Physics of traction



Mass* Acceleration =(Traction – Resistance – slope)

$$M\left(1+\lambda\right)\frac{\mathrm{d}^2 s}{\mathrm{d}t^2}=T-\left(c\left(\frac{\mathrm{d}s}{\mathrm{d}t}\right)^2+b\left(\frac{\mathrm{d}s}{\mathrm{d}t}\right)+a+\frac{d}{r}\right)-\left(Mg\theta\right)$$

Tractive and resistive forces



Summary of traction

- Overall tractive effort is limited by number of driven wheels and maximum torque of the traction motors
- Once the constant power region is reached then the tractive effort drops off with 1/speed
- Possible to achieve good performance with low power and with distributed traction
- Distributed traction also improves regeneration potential

Traction energy overview

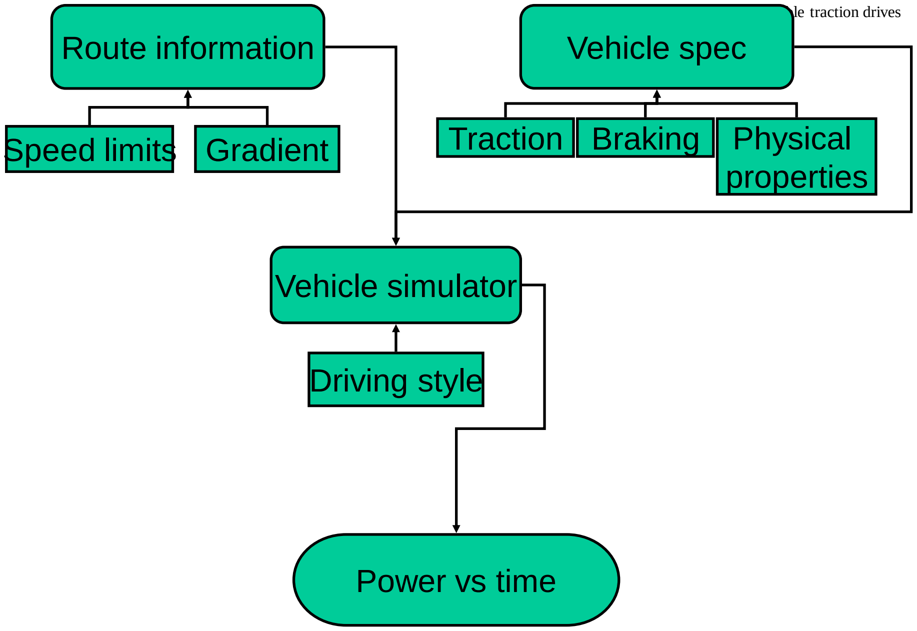
- Energy in at pantograph
  - Auxiliary
  - Traction
    - Losses in:
      - Converters
      - Motors
      - Resistance to motion – slow trains down?
      - **Kinetic energy recovery (last low hanging fruit)**

Options for energy storage 1

- Onboard storage
  - Diesel electric multiple units
  - Diesel multiple units
  - Locomotives
  - Shunting locomotives
  - Electric multiple units

Options for energy storage 2

- Wayside storage (fixed installations)
  - – DC railways
    - Load levelling
    - Regeneration capture and reuse
  - – AC railways – not such an important issue


Route information

Speed limits

Gradient

Vehicle spec

Traction

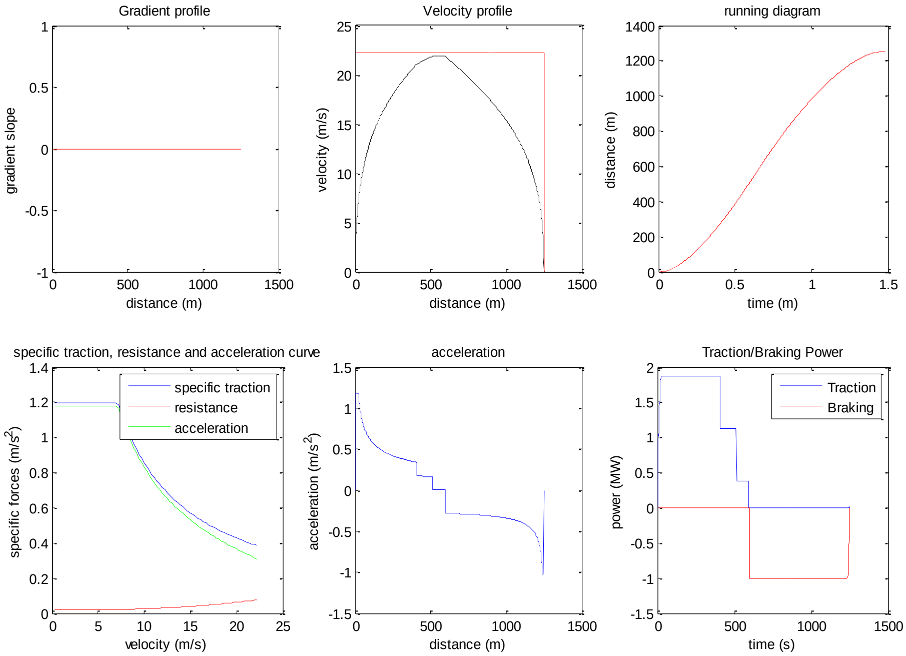
Braking

Physical properties

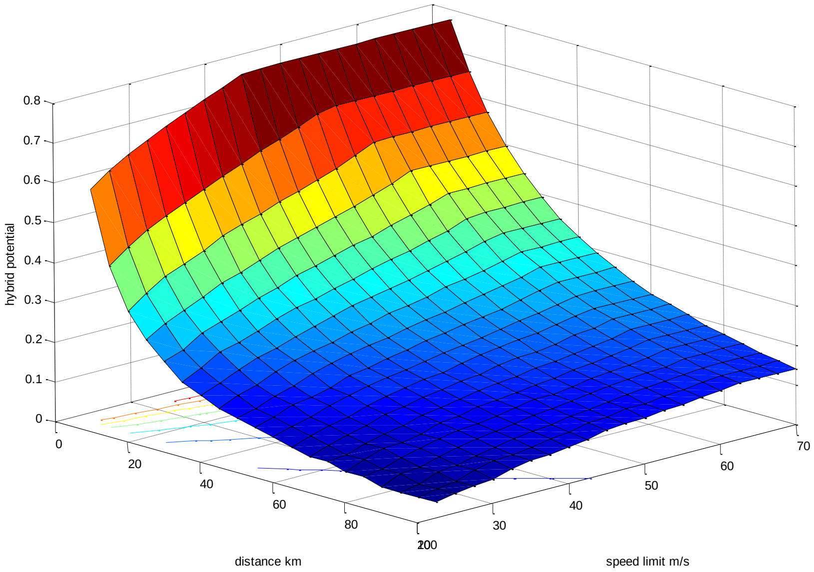
Vehicle simulator

Driving style

Power vs time



Sustainable traction drives



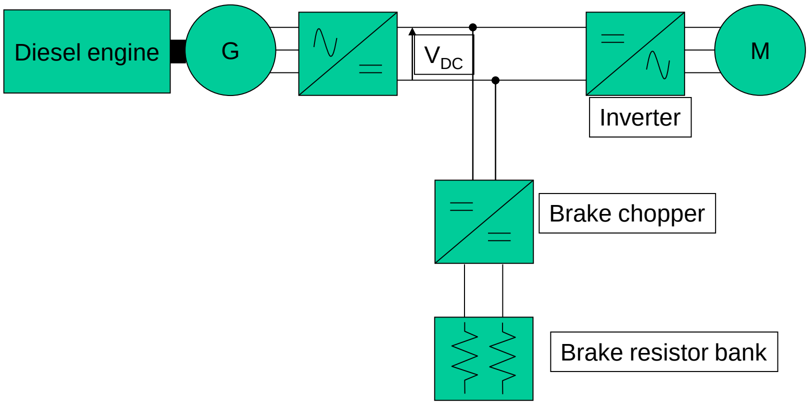
Important features of braking

- At high speed – it is very difficult (impossible) to capture all the braking energy.
- Constant power braking is required to get the most out of regenerating systems
- Using constant power and all electric regeneration will lead to longer journey times – unless you put big machines in the train

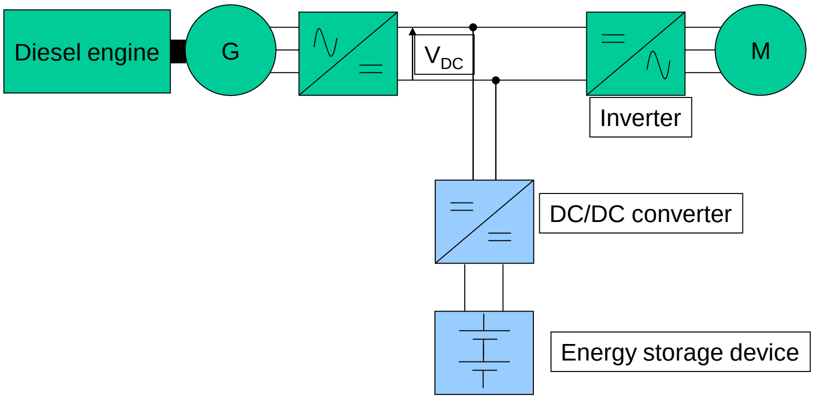
Energy Storage Capability (in MJ/kg)

• Compressed natural gas (CNG):	50 MJ/kg
– But pressure vessel weighs a lot	
• Petrol:	44 MJ/kg
• Diesel fuel:	39-42 MJ/kg
• Ethanol:	30 MJ/kg
• Coal:	29 MJ/kg
• Biomass:	15 MJ/kg
• Liquid petroleum gas (LPG):	45-50 MJ/kg
• Steel flywheel:	0.014 MJ/kg
• Battery:	0.01-0.56 MJ/kg

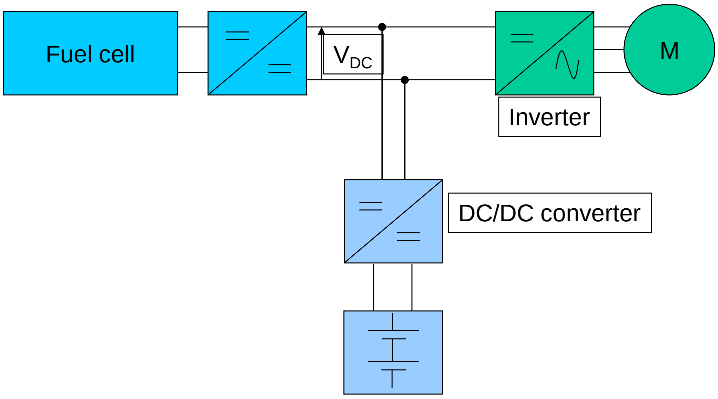
Conventional DEMU



Hybrid DEMU



Hybrid Fuel Cell EMU



Fuel cell

V_{DC}

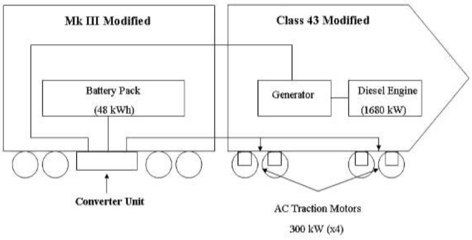
M

Inverter

DC/DC converter

Hayabusa

- Developed by Hitachi, Porterbrook, Brush Traction, and Network Rail.
- Class 43 fitted with 4 Hitachi 300 kW AC traction motors.
- Hitachi lithium-Ion batteries used as the ESD
  - 48 batteries, 960 kg battery weight
  - Capacity: 48 kWh
  - Maximum power output: 1 MW for 170 seconds



Hayabusa series hybrid scheme

EMUs with energy storage

- Provides power in the event of supply failure
- Can improve energy efficiency on DC railways (with long headways and low voltage DC supplies)
- Can power train on sections of track which are not electrified
- No commercial main line trains are currently available – but there are some light rail examples
- IPEMU trial

http://www.railtechnologymagazine.com/Rail-News/prototype-battery-powered-ipemu-carries-passengers-for-first-time

ULEV-TAP2
(Flywheel)

Bombardier
(Ultracap)

- Taken from Professor Rod Smith, Imperial College London,
- IMechE December 2008

Wayside energy storage

- Essentially same principles apply:
  - Need to consider the supply duty cycle
  - Careful positioning of equipment
  - Range of storage technologies to consider
    - Capacitor
    - Battery
    - Flywheel
  - Can lead to energy savings – but these are harder to realise in an electric railway – and the economic case is not there yet.

Verification Test of Energy Storage System for DC 750V Electrified Railway

Takeshi Konishi*, Shin-ichi Hase*, Yoshinobu Nakamichi*,
Hidetaka Nara**, Tadashi Uemura**

RTS 2007 (The Third International Conference on Railway Traction Systems), Tokyo, Japan

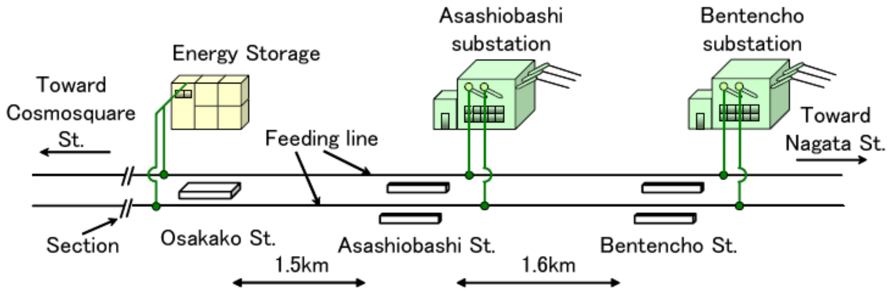


Fig. 1. Test section.

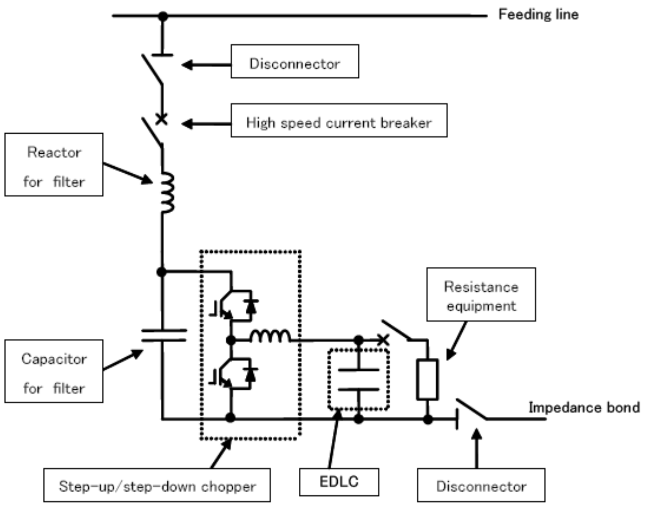


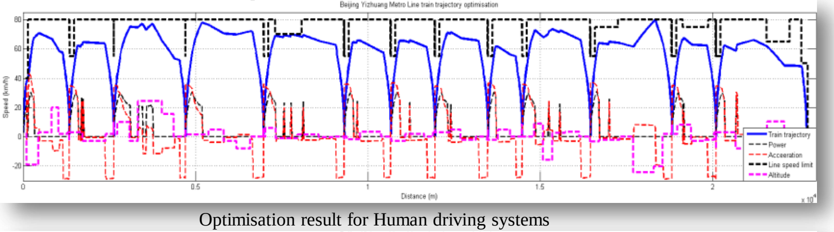
Fig. 2. Main circuit.

Sustainable traction drives

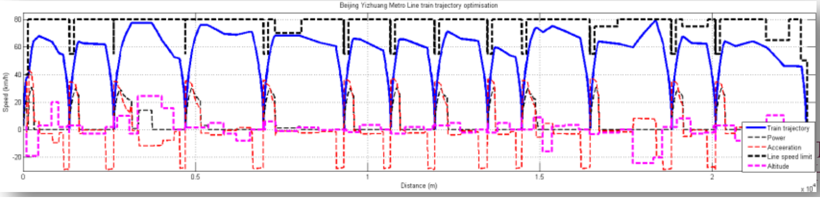
Single train trajectory optimisation –BJMTR case study-

Real train trajectory		**Train trajectory optimisation**				**Train trajectory optimisation + Journey time disturbance optimisation**			
ATO system		**Human system**		**ATO driving system**		**Human system**		**ATO driving system**	
Journey time (s)	**Energy usage (kWh)**	**Journey time (s)**	**Energy usage (kWh)**	**Journey time (s)**	**Energy usage (kWh)**	**Journey time (s)**	**Energy usage (kWh)**	**Journey time (s)**	**Energy usage (kWh)**
1630	380.6	1630	310.8 （-18%）	1630	308.8 (-19%)	1630	304.3 (-20%)	1630	304.5 (-20%)

Optimisation result for ATO systems



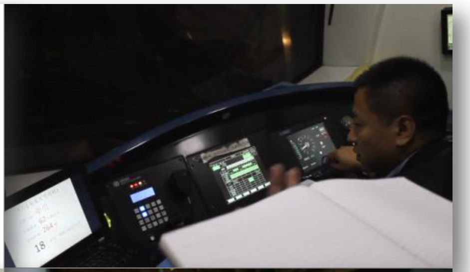
Optimisation result for Human driving systems



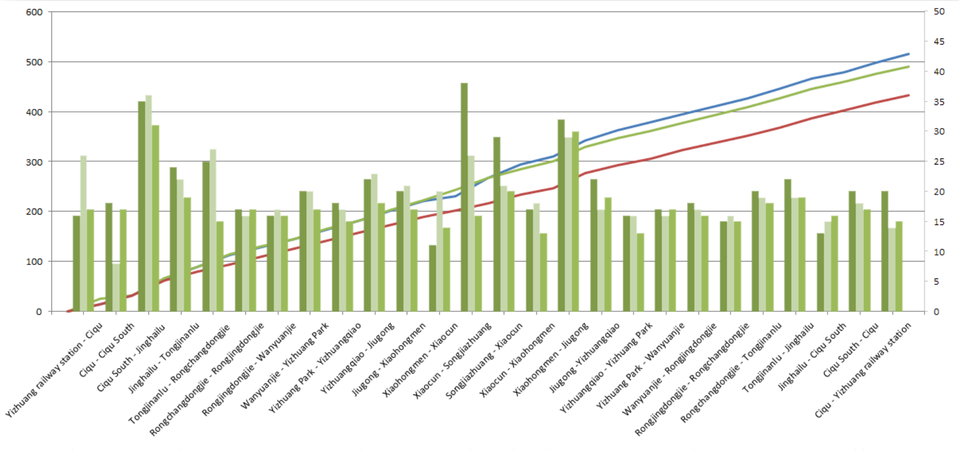
Sustainable traction drives

Beijing Yizhuang Metro Line field test

上行1：亦庄火车站至次渠1
Up direction: Yizhuang Railway Station to Ciqu
当前工况：牵引
Current movement mode: Motoring
目标速度：35 公里/小时
Target speed: 35 km/h
目标距离：79 米
Target location: 79 km/h
12 秒后，转换工况为巡航
Seconds later, change to Cruising

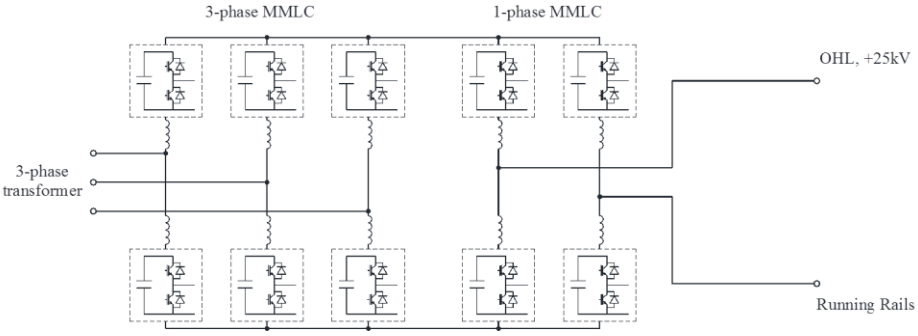


Sustainable traction drives

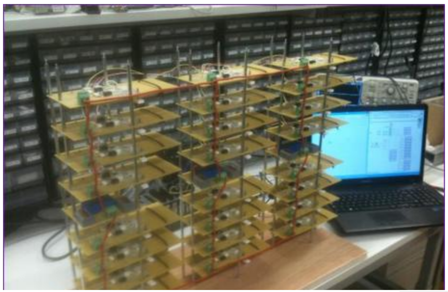


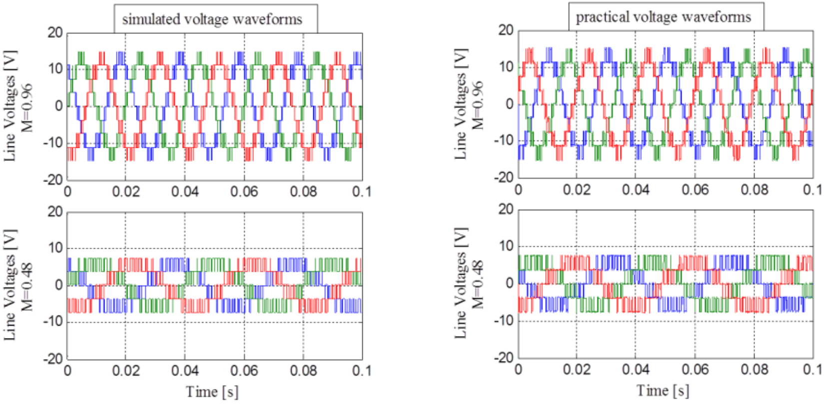
Sustainable traction drives

Power electronic substations



Sustainable traction drives





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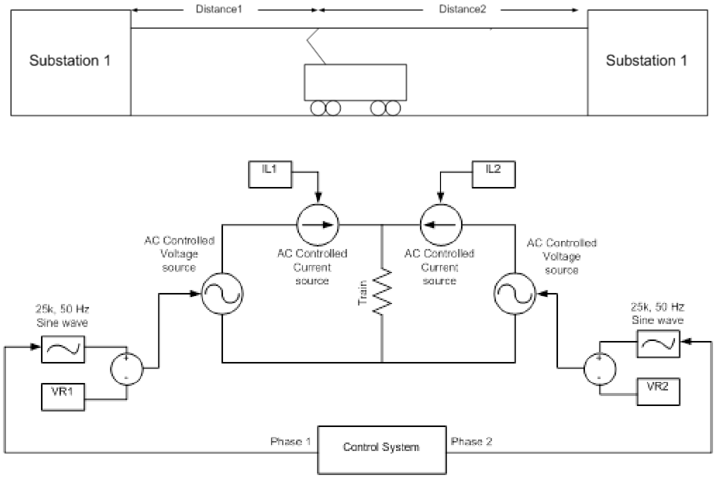

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And for where we don't electrify we have the option of fuel cell trains

- Benefits of electrification without OLE
- Zero emissions at point of use
- Lots of ways of making the H_2

Summary

- Railway traction is fundamentally sustainable
- Kinetic energy recovery can improve overall energy efficiency
- Energy storage solutions are being trialled in many different railway applications
- The economic case is still a bit uncertain
- The performance of energy storage is likely to improve and we are likely to see wide scale implementation of these systems in the future
- Duty cycle is the most important factor to consider when thinking about energy storage devices
- Power electronic traction substations have the possibility to revolutionise the railway power system and be a key part of the smart railway power grid