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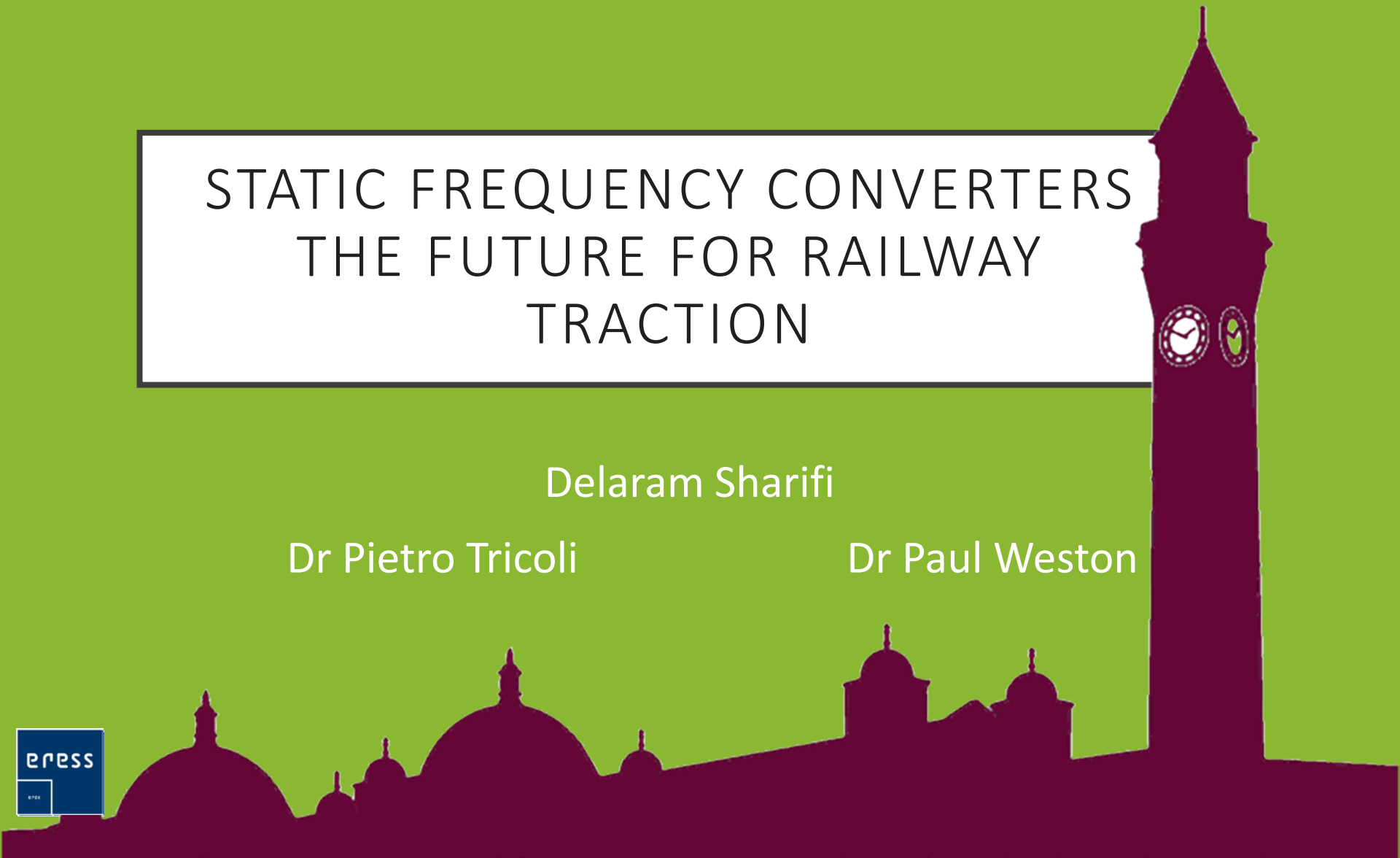
STATIC FREQUENCY CONVERTERS THE FUTURE FOR RAILWAY TRACTION

Delaram Sharifi

Dr Pietro Tricoli

Dr Paul Weston



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THE FUTURE FOR RAILWAY TRACTION

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- Many European governments are committed to investing in further electrifying their railway networks.
- Industries, supported by university researchers, are looking into alternative electrification systems for new and existing railway lines around the world
- Static Frequency Converters (SFCs) have been recognised as the future as feeder-station for railway traction systems due to their numerous benefits.

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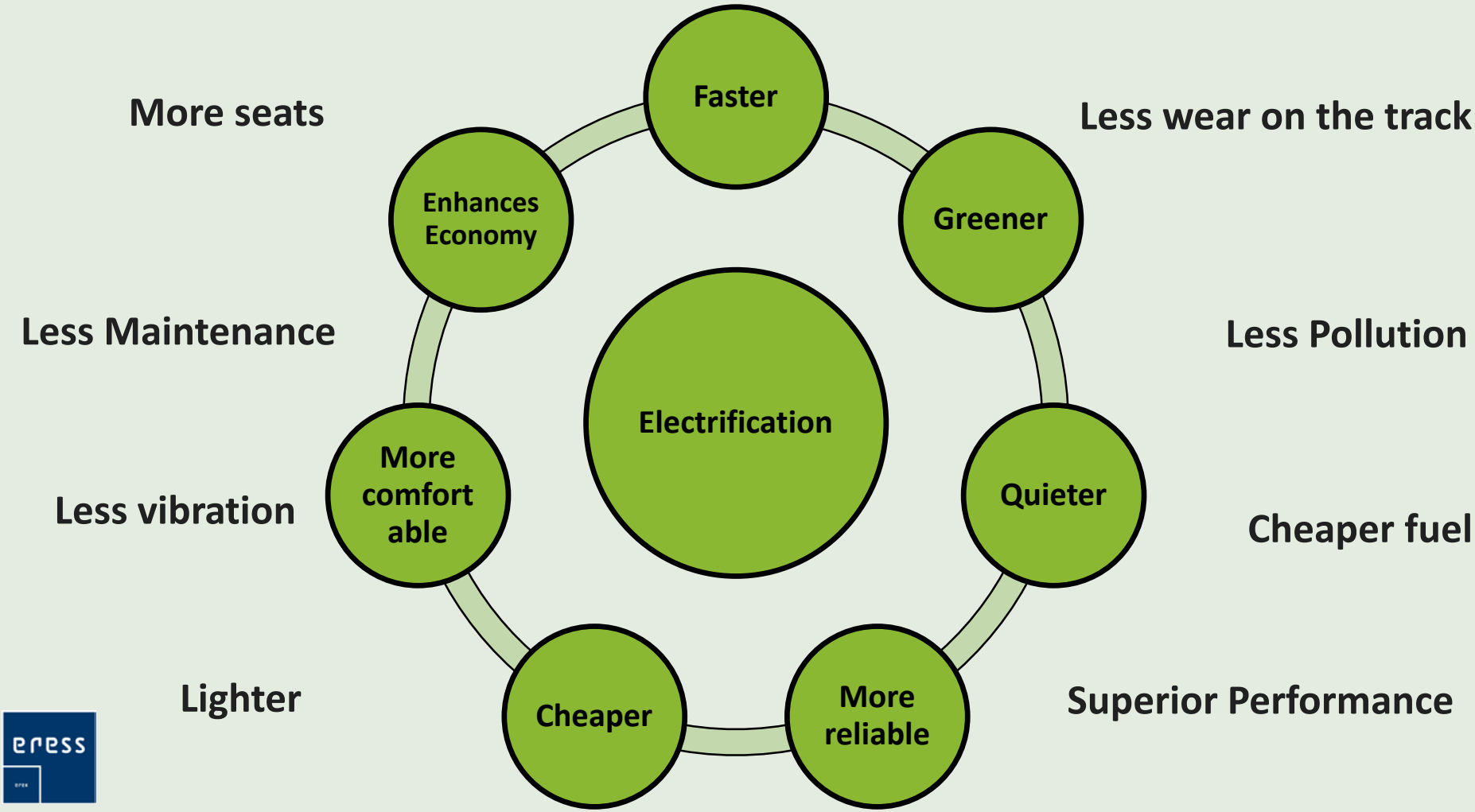
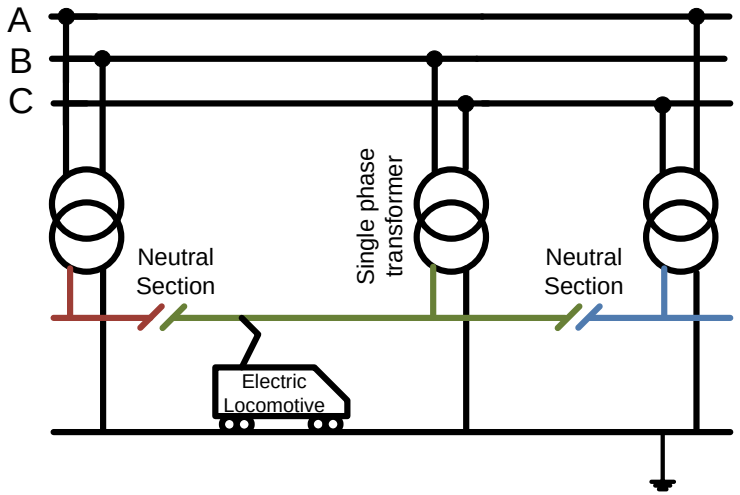
WHY ELECTRIFICATION?



CURRENT ELECTRIFICATION SYSTEM TRANSFORMERS

- **Static imbalance**
  - Special transformers to reduce imbalance
  - Connection to high voltage lines(135 kV) to limit the effects of imbalance
- **Low frequency harmonics**
- **Rated for peak power**
- **Require neutral sections**
- **Low power factor at light loads**



Single-phase transformer feeder stations

STATIC FREQUENCY CONVERTERS BENEFITS

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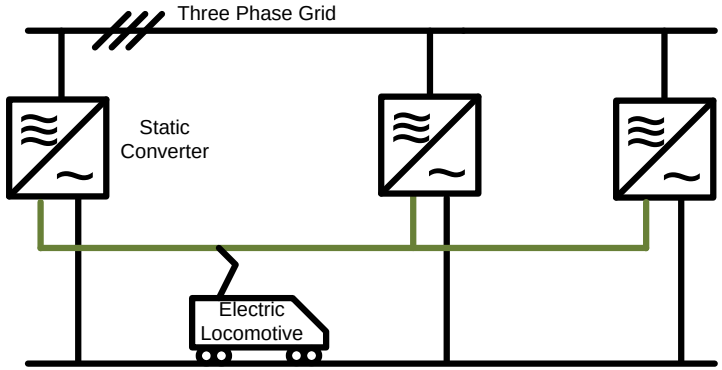
- Mesh feeding ⇒Substations can be placed further apart, Renewable input possible
- No Imbalance ⇒No connection to high voltage grid required
- Active voltage regulations, Power factor control ⇒ Lower Losses
- Controllable voltage magnitude and phase⇒ Smart Control
- Lower rating Possible small or no filtering ⇒Lower cost / weight / maintenance



Static converter feeder stations

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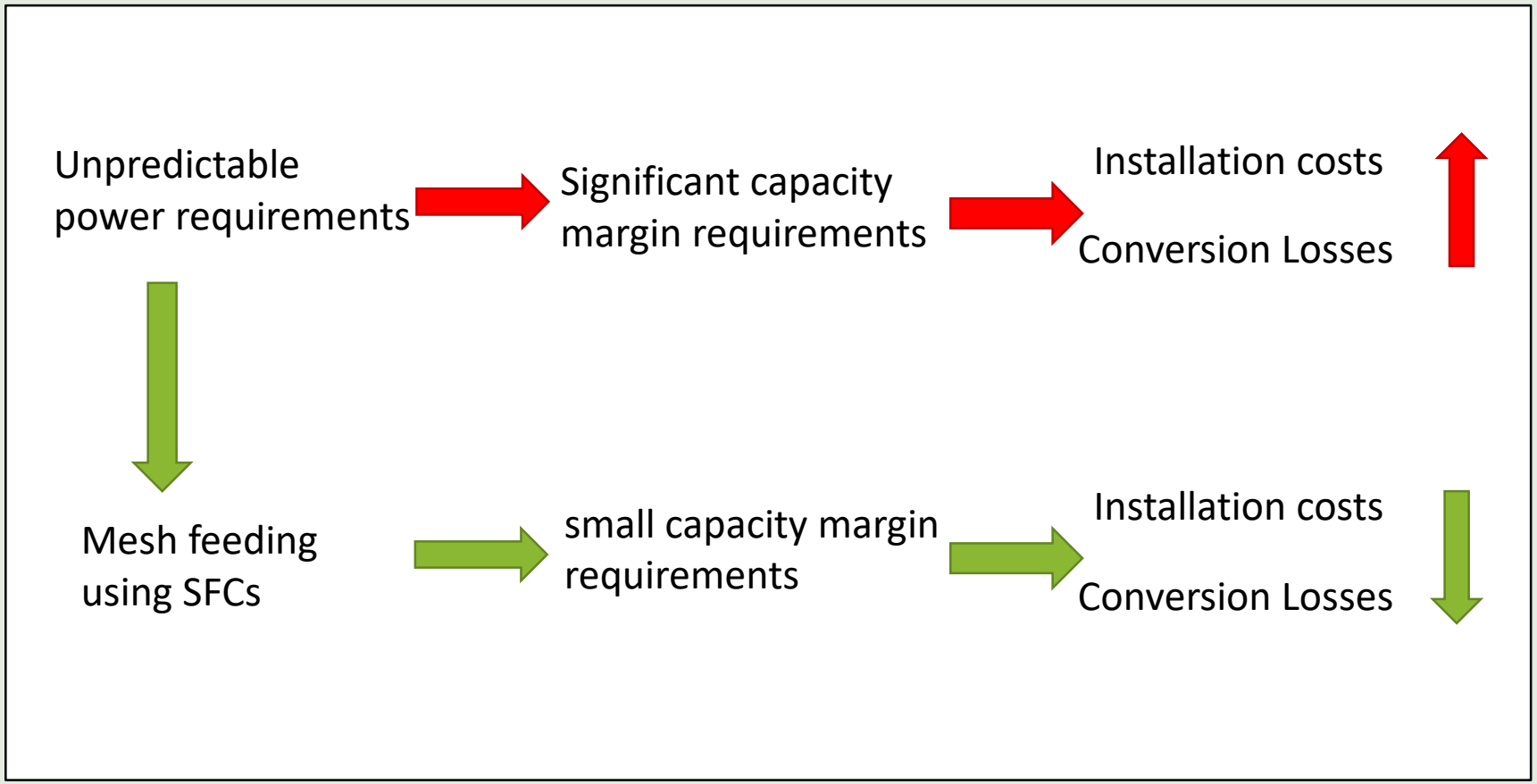
CONVENTIONAL FEEDING SYSTEM VS SFC FEEDING SYSTEM



CURRENT SFC SYSTEMS

- In Germany, Switzerland, Sweden, Austria and Norway, where the railway network operates at 15 kV, 16 2/3 Hz, SFCs are well established and have replaced in many cases rotary converters.
- Single-phase networks are controlled with equal phase angles of the feeder-stations at all times in order to guarantee high dynamic of the electrification system
- SFC based feeder-stations have found application also to 50 Hz railways in Queensland, Australia where the output voltages are also operated with the same phase angles

CURRENT SFC CONTROL (WITHOUT SMART CONTROL TECHNIQUES)

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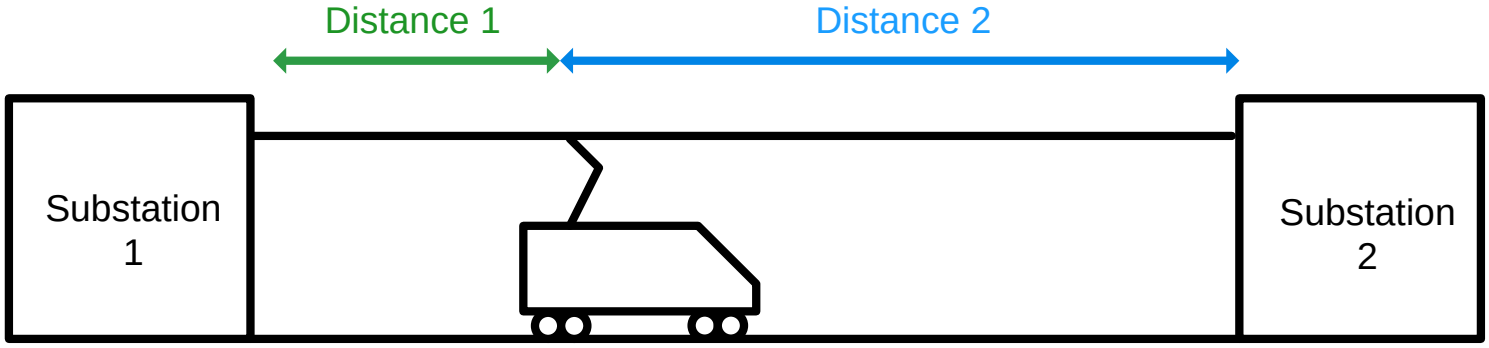
- Without any control of the voltage of the two feeding points, the train draws a percentage of power that is inversely proportional to the distance from each substation
- Each substation must have the capacity to individually feed 100% of the train's power requirement

Not Optimal!



PROPOSED SOLUTION

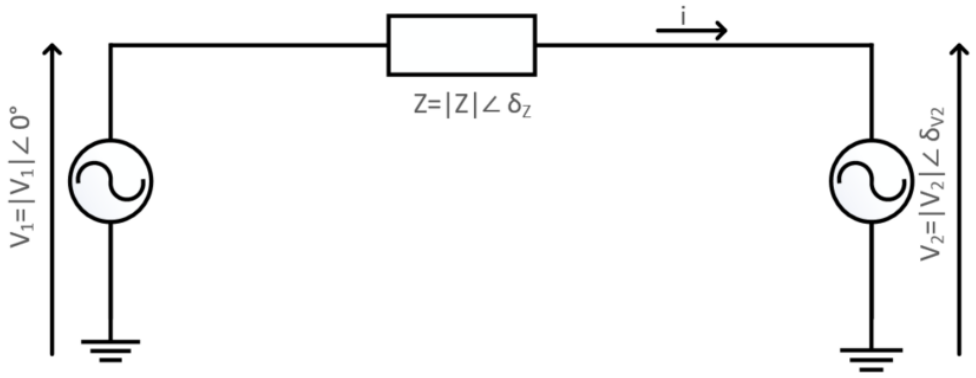
A new smart control method in which the feeder stations provide an equal share of the trains network's active power while limiting the reactive power regardless of the position of the train on the track.

- This method optimises the maximum load on the substations leading to :

Already existing lines : Increase in train capacity on the line

New build lines : Decrease in required substation capacity

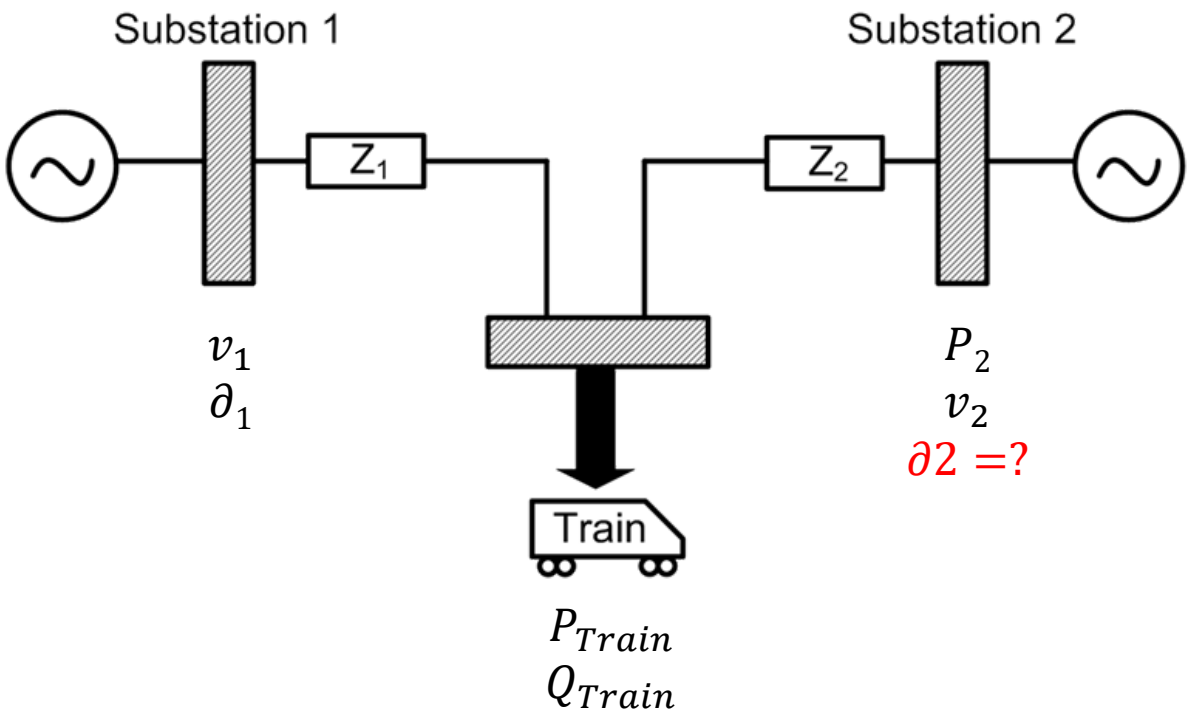
CONTROLLING ACTIVE AND REACTIVE POWER BY PHASE ANGLE AND VOLTAGE MAGNITUDE



$$P_1 = \Re\mathrm{e}\,\{v_1 i^*\} \Rightarrow P_1 \propto \delta_{v2} - \delta_{v1}$$

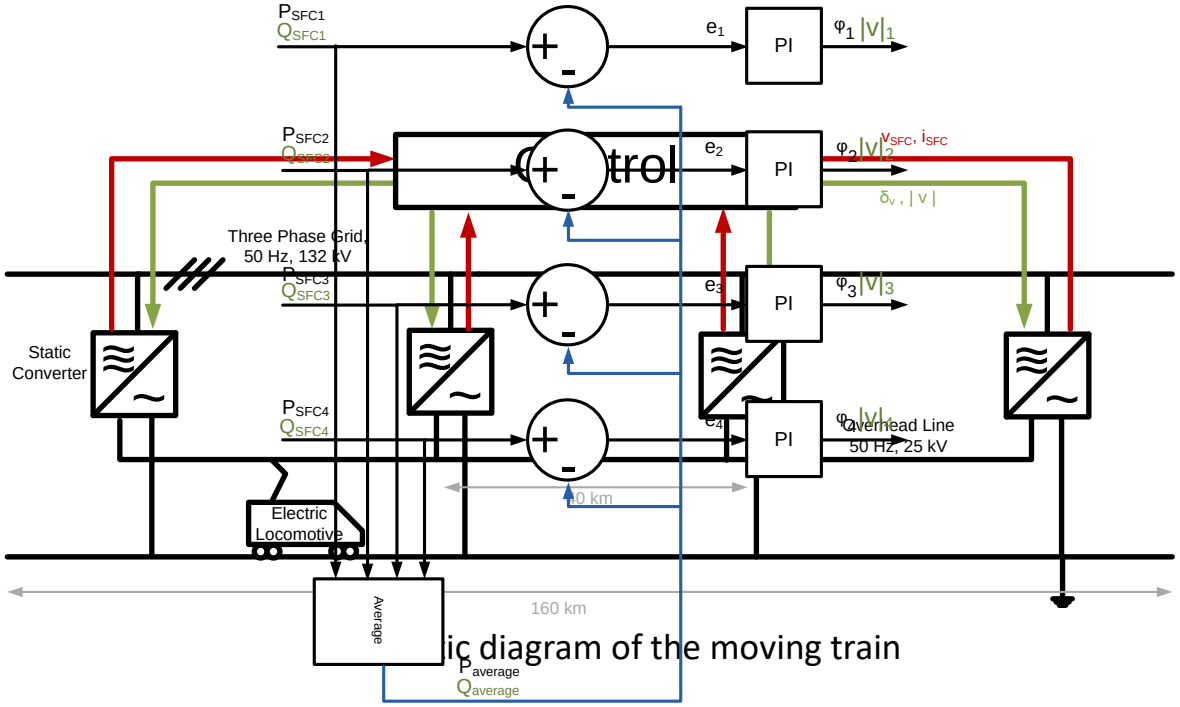
$$Q_1 = \Im m\{v_1 i^*\} \Rightarrow Q_1 \propto |v_1| - |v_2|$$

CALCULATING THE PHASE ANGLE AND MAGNITUDE OF VOLTAGE



PI CONTROLLER IMPLEMENTATION

A PI (proportional–integral) control system is designed to control the value of each substation's magnitude of voltage and second, third and fourth substation's phase angle.

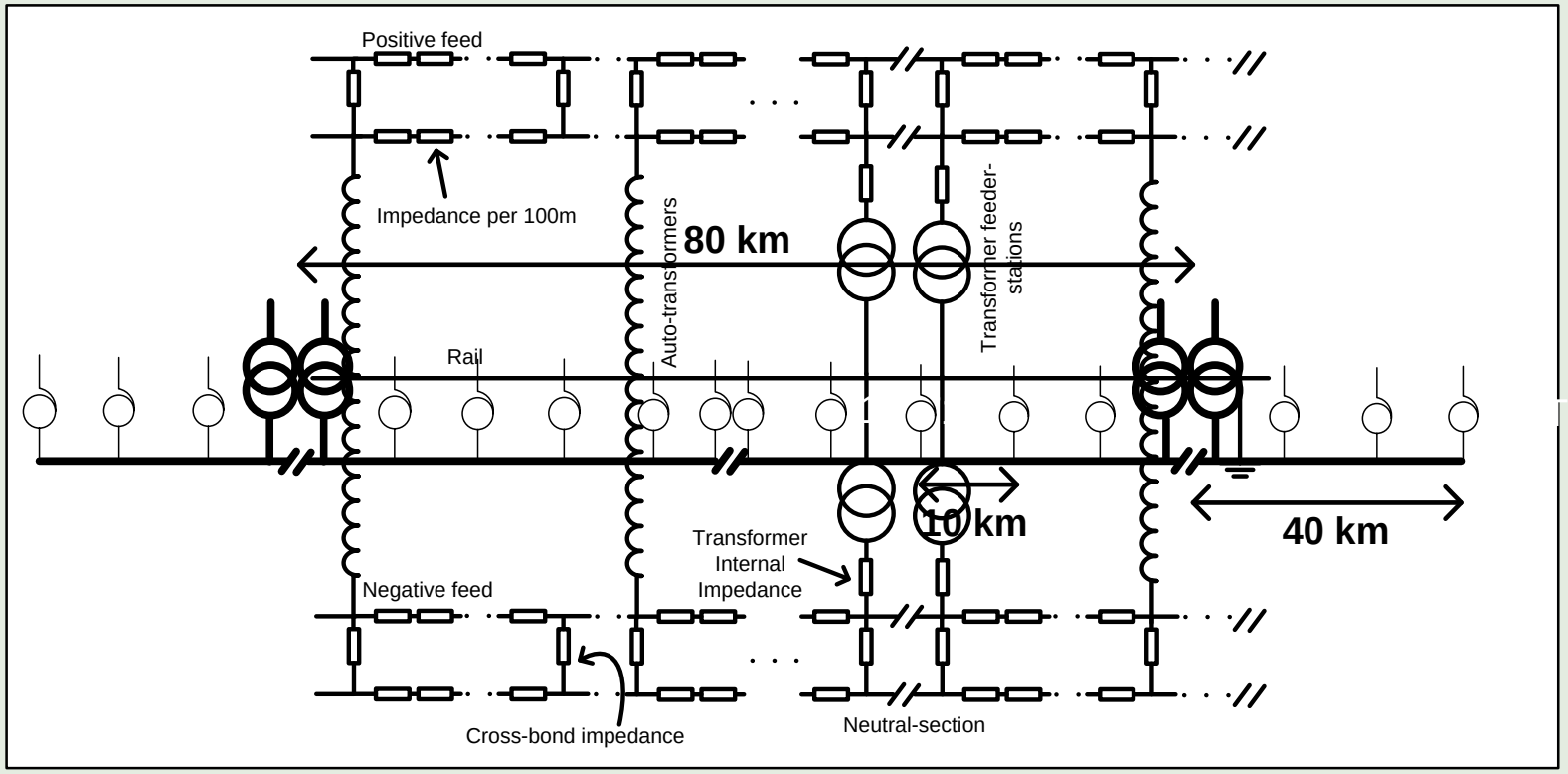


ic diagram of the moving train

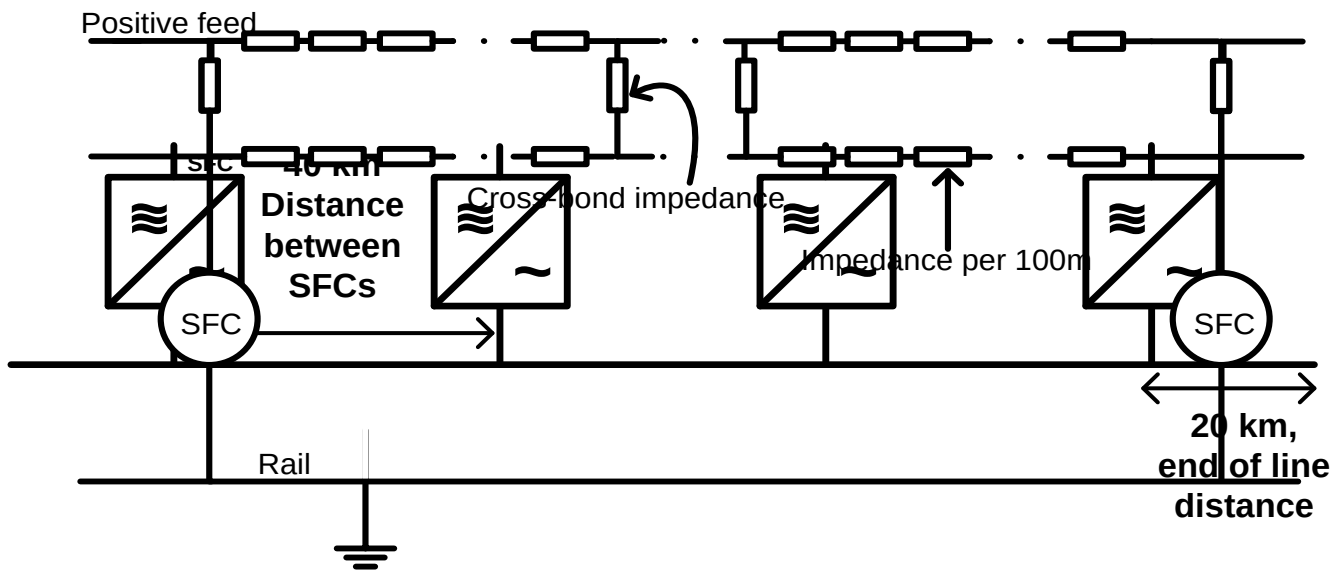
MATHEMATICAL MODEL

- MATLAB Script
- A Network of moving trains analysed in three comparable scenarios:
  - Auto-Transformer System
  - Static converter system – Synchronised
  - Static converter system – Equal share
- 160 km Journey
- The train is assumed to be a 6.1 MW Pendolino
- Time table of trains implemented with 5 stops.
- Acceleration, deceleration and regenerative power is taken into account.

AUTO-TRANSFORMER MODEL



STATIC CONVERTERS MODEL



SIMPLE COMPARISON BETWEEN THE SCENARIOS

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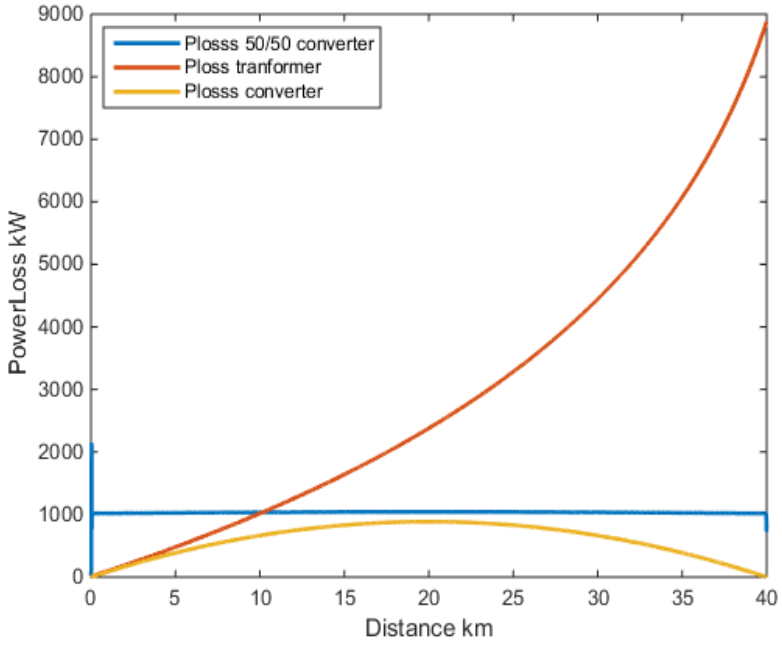
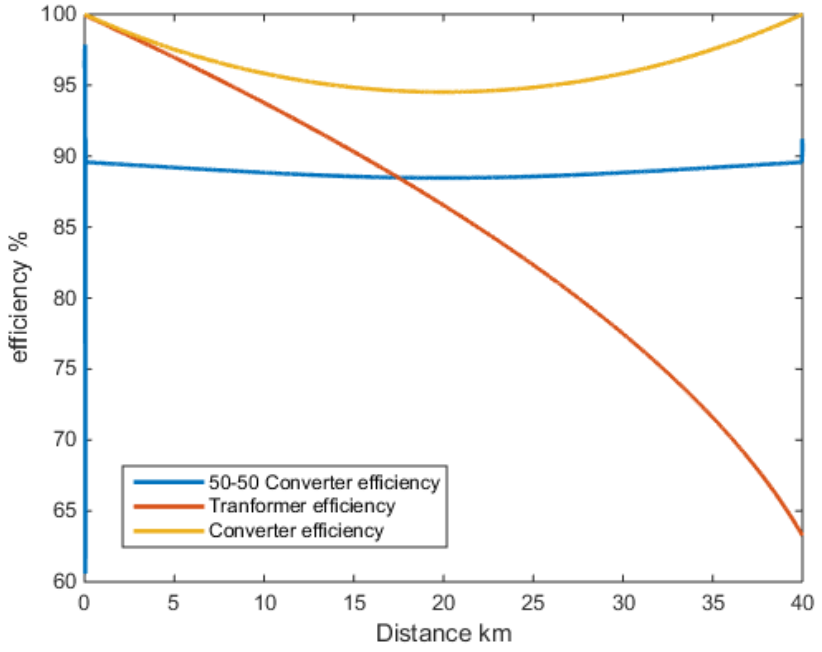
- Powerloss and Efficiency





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TIMETABLE OF TRAINS

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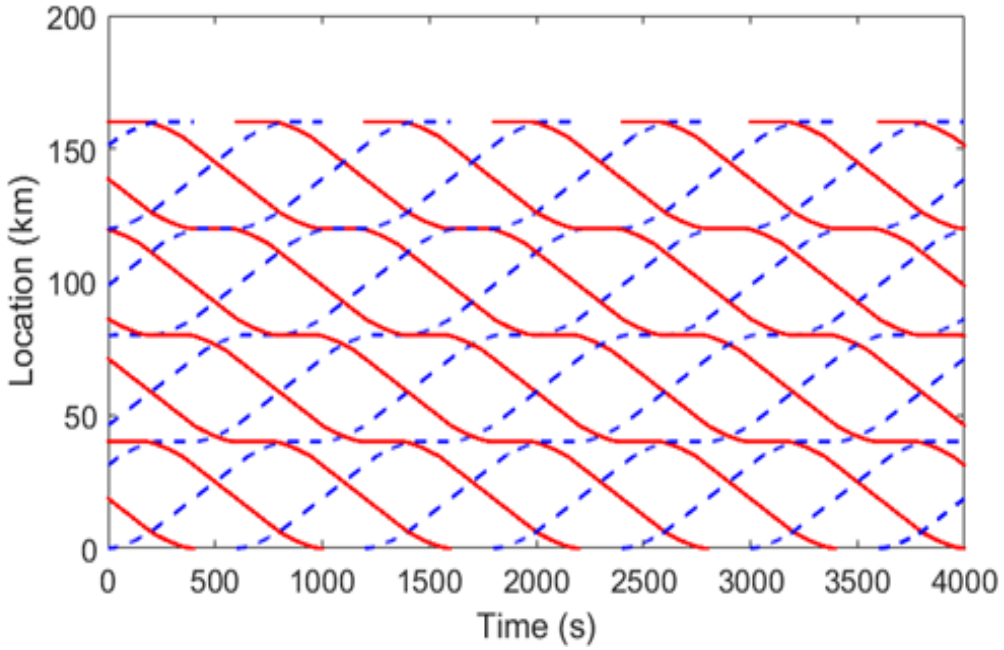
- 14 trains on the line.
- 8 minutes gap between the trains, 3 minutes stop at the station
- Real data has been used to simulate the acceleration and deceleration time and power requirements



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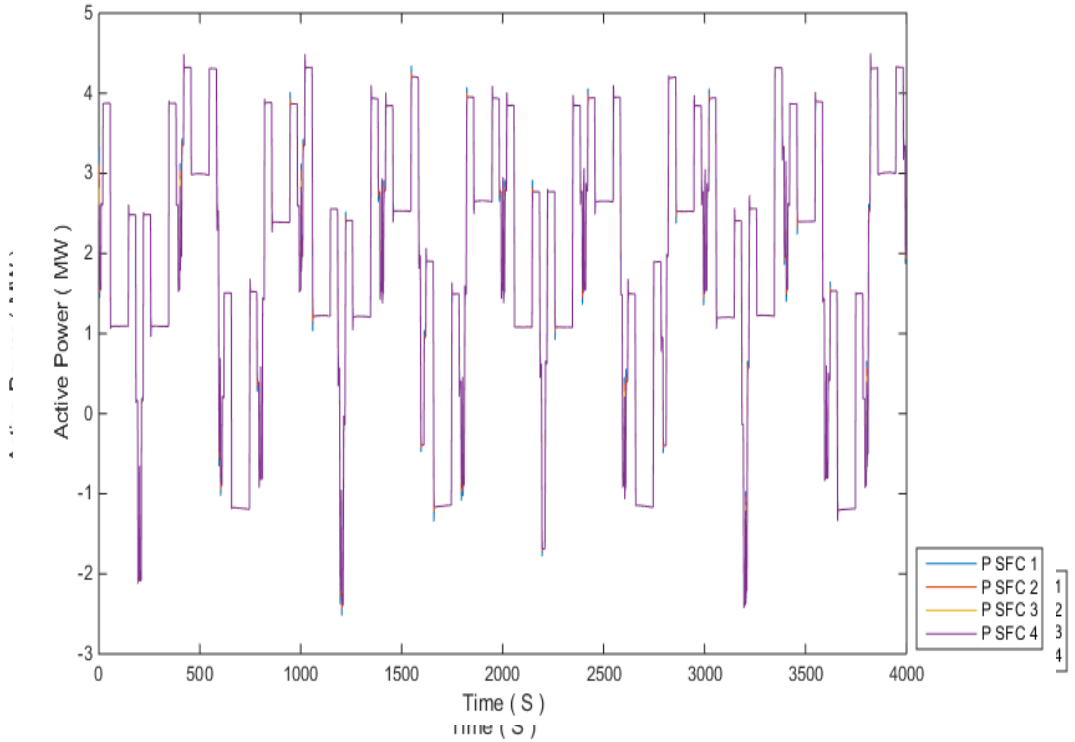
ACTIVE POWER GRAPHS

- AT System
- SFC-Synchronised
- SFC-Smart control



THE EFFECT OF DISTANCE BETWEEN SFCS ON MAXIMUM INSTANTANEOUS POWER AND ENERGY LOSS

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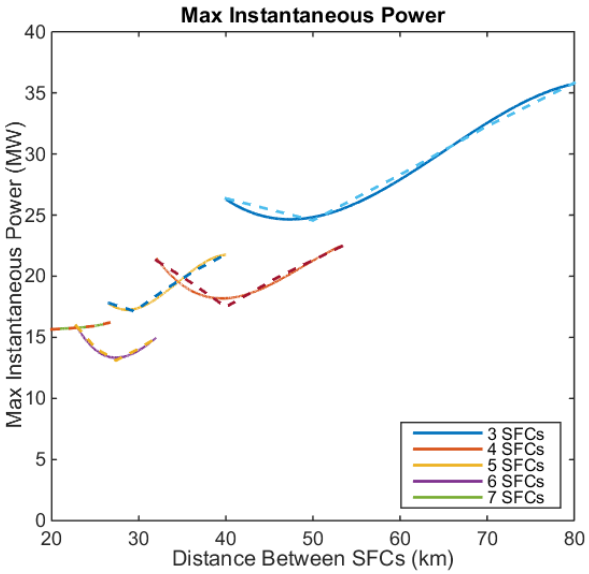
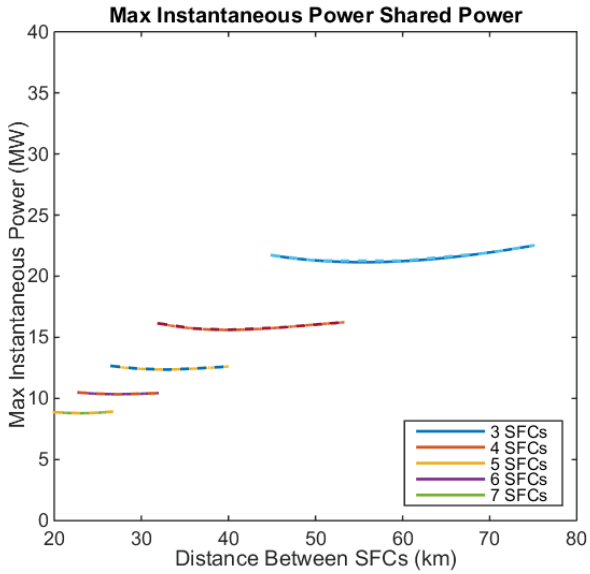
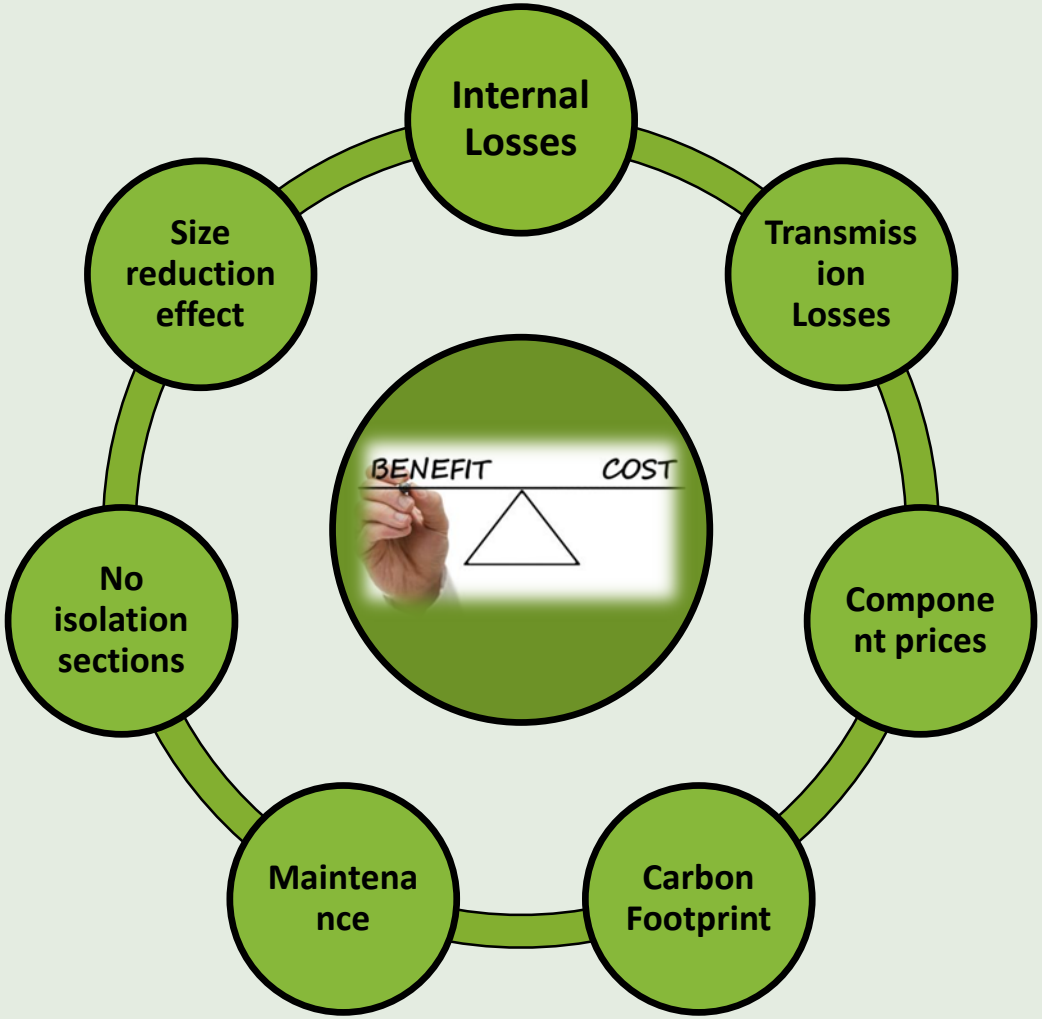
- Energy lost in transmission
- Maximum instantaneous power





FEASIBILITY



FUTURE WORK

- A Comprehensive cost-benefit analysis for a full network of trains
- Although the equal share of power does not increase the transmission energy efficiency of the line, the arrangements in which the cost efficiency and energy efficiency are optimum should be investigated through further studies.
- Effects on the control system caused by the delay in the transmission of the feedback signals should be studied.

CONCLUSION

- SFCs represent the future for the electrification of railway lines
- Feeder stations will be provided with “intelligence” to optimise the operations of the train and the interface with the grid network
- Integration of renewable sources and storage is possible with power converters
- With power converters a new concept of “smart railways” will be introduced

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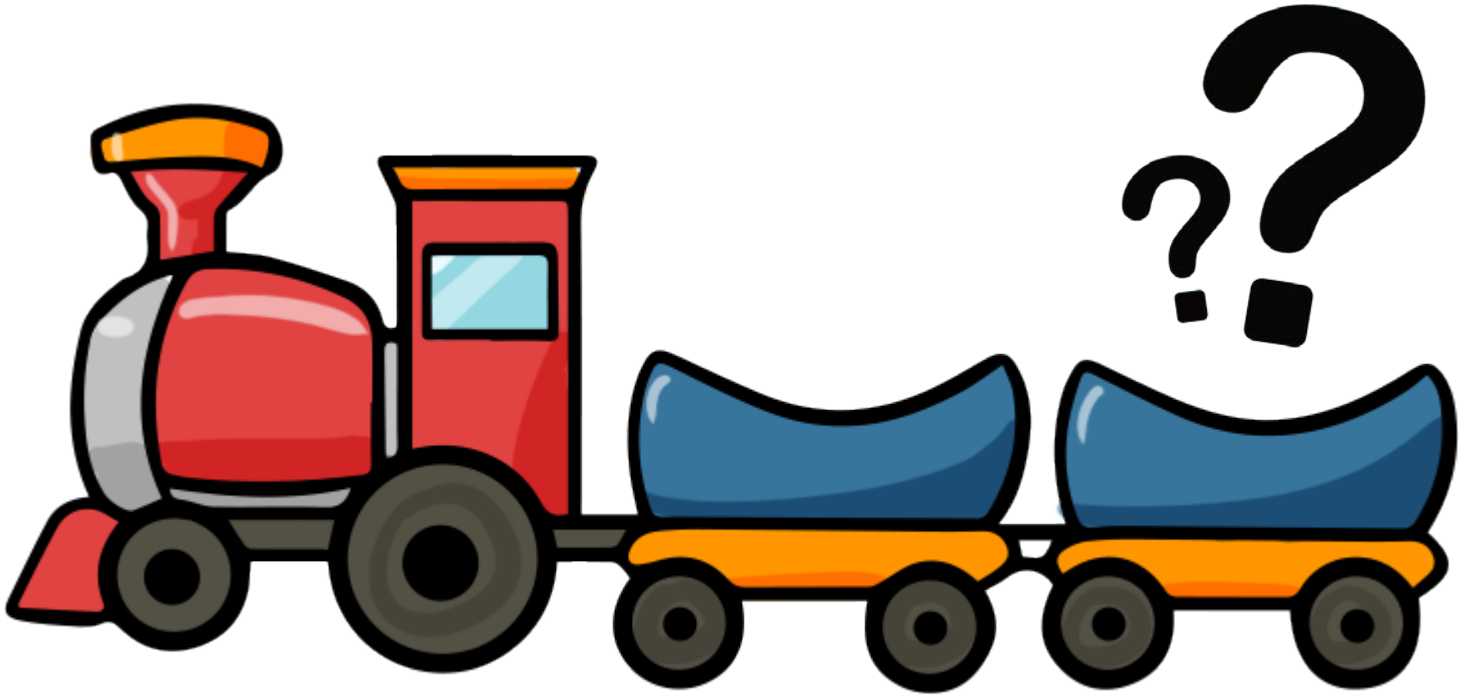
ANY QUESTIONS ?



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