Advanced system architectures and operational methodologies leading to energy efficient operations in the new Metro Line 4 in Athens

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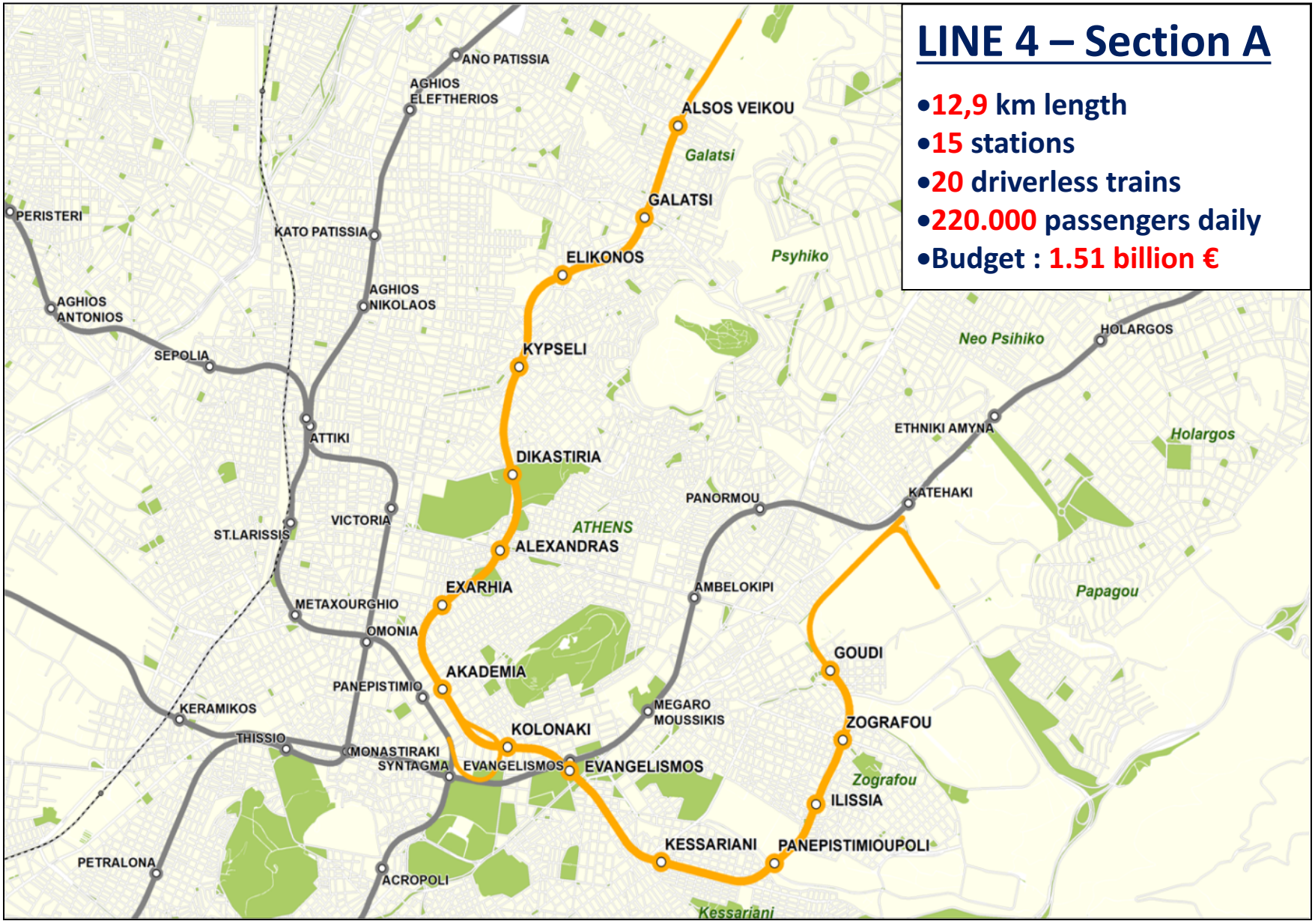
Outline/Agenda

- **Present the new Athens Metro Line 4 project**
- **Outline the energy saving and energy optimization concepts for the new Metro line**
- **Present in more detail the energy saving and energy optimization concepts, which are made possible by :**
  - **Upgraded capabilities of IT technology,**
  - **Latest electrical power systems control and state of the art computer controlled automations for trains and systems**
  - **Use of new materials and products**
  - **Classic energy saving solutions applied on new systems and new trains**
  - **Conditioned Based Maintenance**
  - **Minimizing the Carbon Footprint**
- **Conclusions**



LINE 4 – Section A

- 12,9 km length
- 15 stations
- 20 driverless trains
- 220.000 passengers daily
- Budget : 1.51 billion €

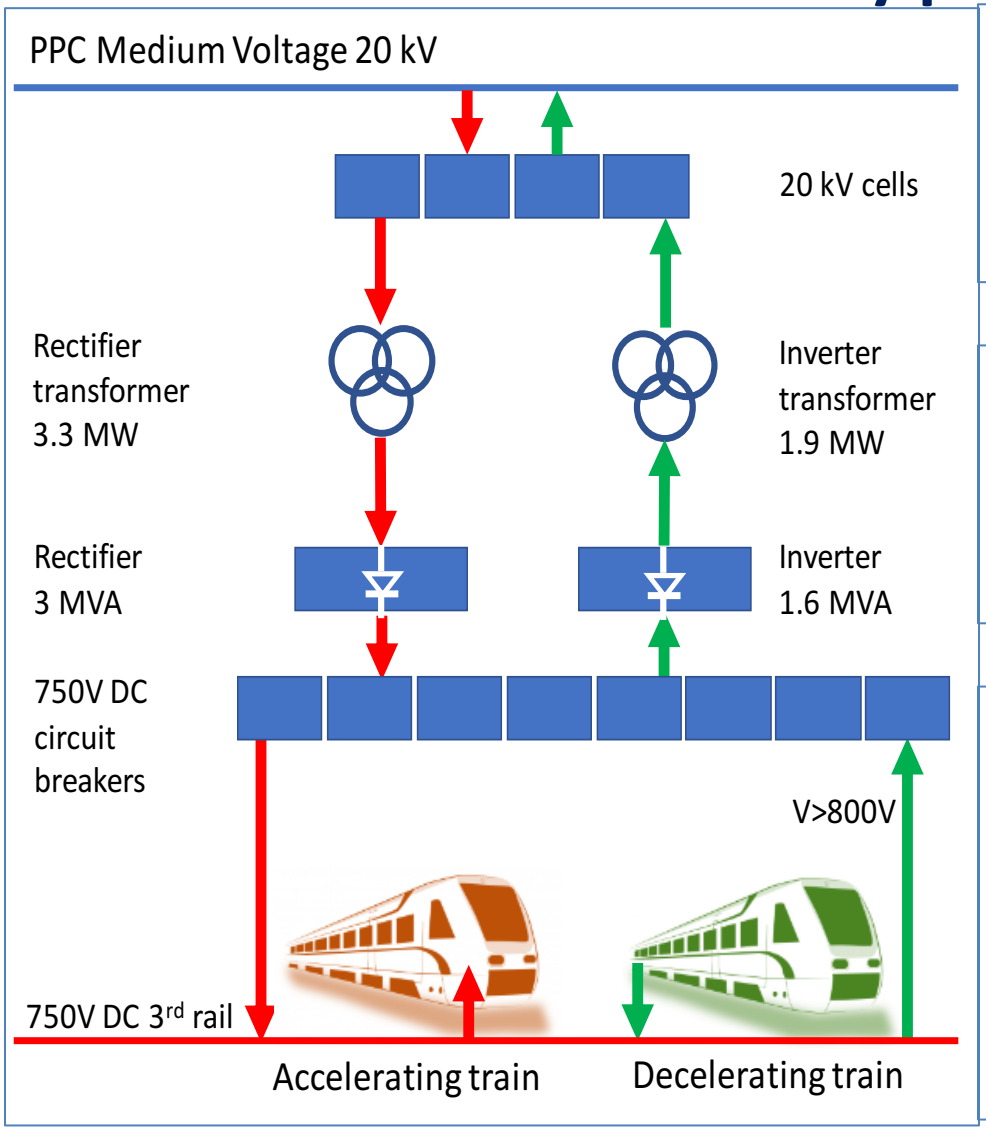
Energy sustainability concept for Metros

- A Metro system offers a excellent example of energy, environmental, cost and social sustainability by reducing city traffic loads, consumption of energy, passengers travel time, pollution emissions, car accidents, noise levels, etc., while promoting sustainable growth
- Makes worthwhile the substantial capital cost necessary to construct a Metro Line (≈100 m € / Km)

Line 4 Energy Optimization Concepts

- Train Braking Regenerated Energy Return to the city power grid
- Train movement optimization for maximum regenerated energy re-use by other trains
- Dynamic Train Headways Modulation based on on-line passenger counting
- Informing passengers on station platforms on the loading of trains cars
- New tunnel ventilation scheme
- Humped profile in the tunnel vertical alignment
- Cosine correction in power substations
- Use of LED lighting and advanced lighting control techniques
- SCADA and Systems Automations
- Use of high efficiency motors
- Conditioned Based Maintenance
- Minimizing the Carbon Footprint

Braking Regenerated Energy Return to the city power grid

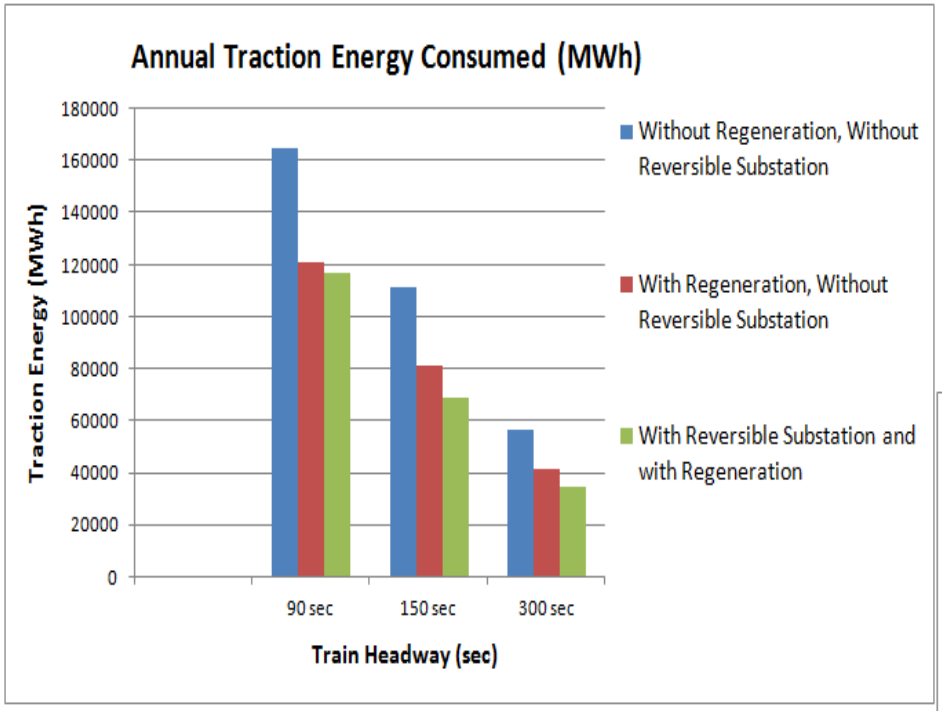


When a train brakes, the motors are instantly turned into generators and generate electrical energy from the kinetic energy of the train. This is raising the line voltage in the 3rd rail above the nominal 750 V and up to 900 V.

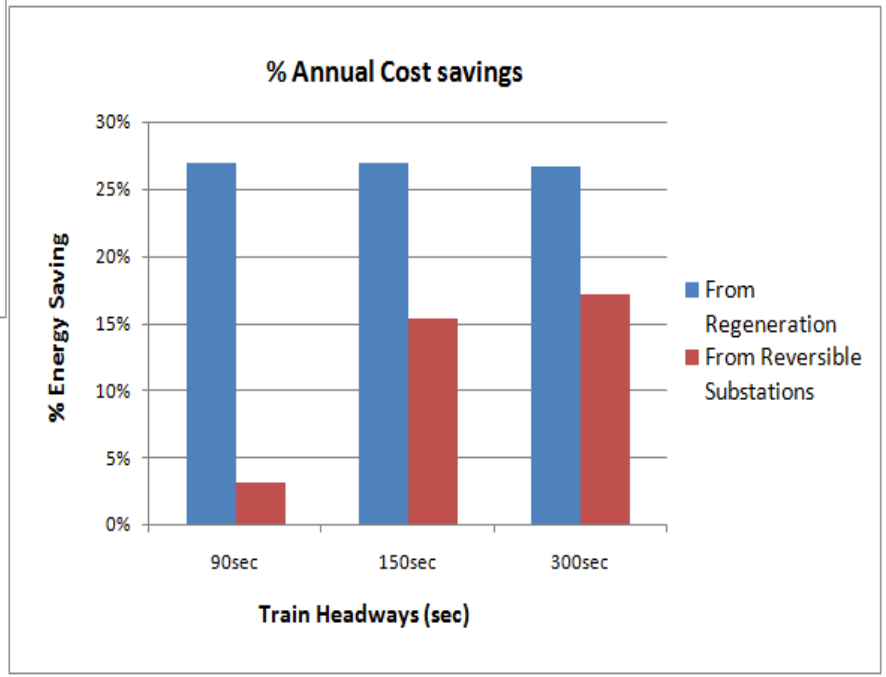
If another train is in the vicinity it uses this energy. If not, when the line voltage exceeds 900 V due to braking then this energy is directed to resistors that heat up to 400 deg C and consume this energy as heat.

According to the new scheme, when the line voltage generated, exceeds a certain threshold value (eg 800 V), then the regenerated DC current fed to the 3rd rail, is inverted into AC using an inverter, then stepped up to 20 kV using a transformer and fed back to the city Medium Voltage 20 kV grid.

Braking Regenerated Energy Return to the city power grid

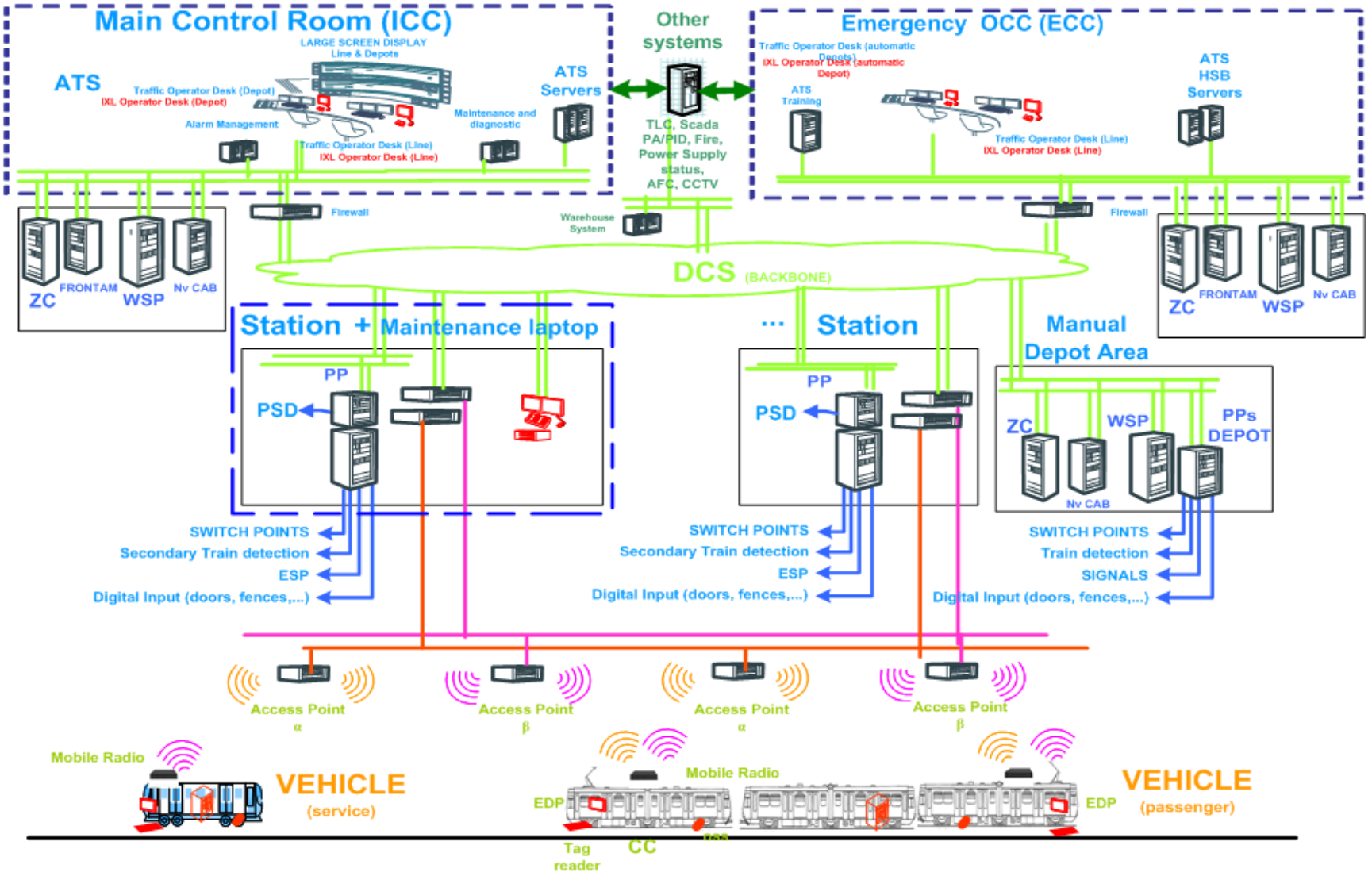


For typical train headways of 150 sec, a 15% of traction energy saving is expected.

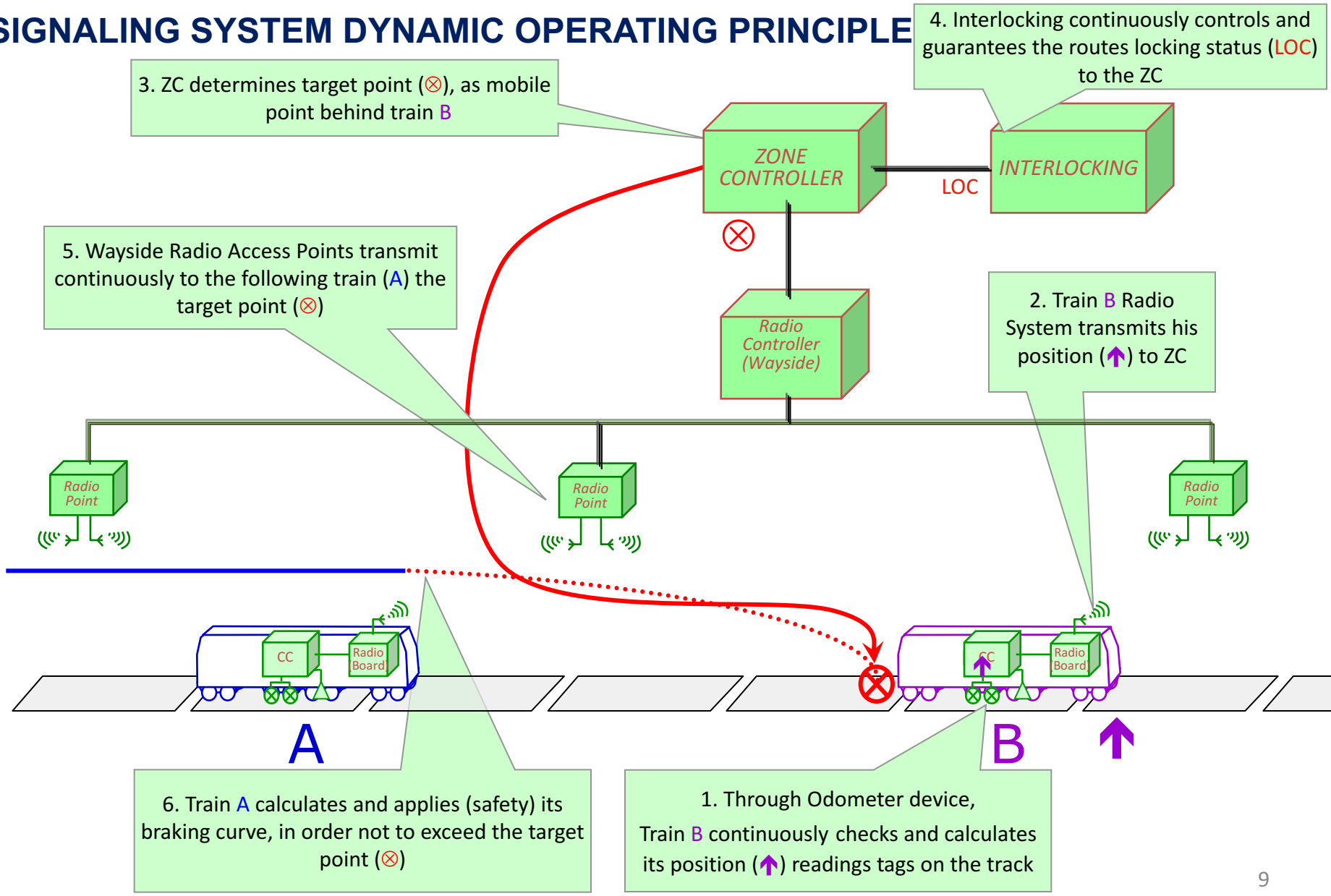


The cost in Euros of the returned energy is estimated to be of the order of 1 million € / year

Signaling System Train Movement Optimization for maximum regenerated energy re-use by other trains



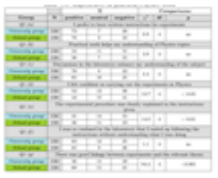
SIGNALING SYSTEM DYNAMIC OPERATING PRINCIPLE



Dynamic Train Headways Modulation based on on-line passenger counting

Gates - passengers counting | Station CCTVs | Train on board CCTVs | Events information | Passengers statistics



DATA COLLECTION

PRINCIPLE : Driverless trains may be deployed for automated operation from the Control Centre based on the actual passenger numbers entering the system

CONTROL CENTRE SUPERVISOR

SIGNALING – ATS TRAIN CONTROL

DYNAMIC TRAIN HEADWAYS MODULATION

PASSENGER INFORMATION DISPLAYS

- A train typically consumes 15-20 KWh of energy to move from one station to another
- Hence for every train saved (not deployed for operation) energy is saved too.
- The target is to carry "more people and less metal" per train trip

Informing passengers on station platforms on the loading of approaching trains cars

Train Stops at Platform - doors open Passengers enter

Every train car measures its weight

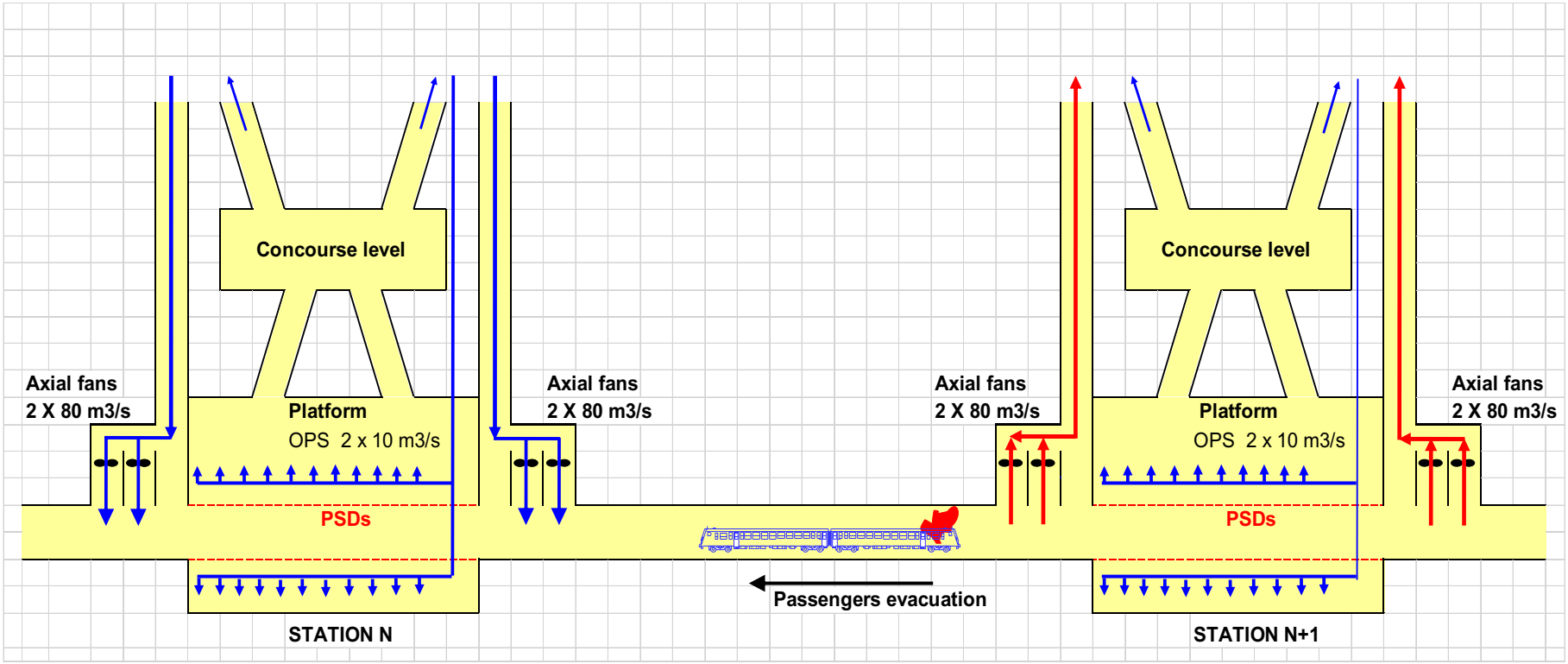
The car weight information is transmitted through the Radio and the Wireless Data Communication systems (RCS-WDCS) to the next station

The weight information of each train car is displayed with a coloured bar in the respective Passengers Information Display System (PIDS) above the PSDs.

Passengers enter at the less loaded train cars in the next station – more comfort, less time

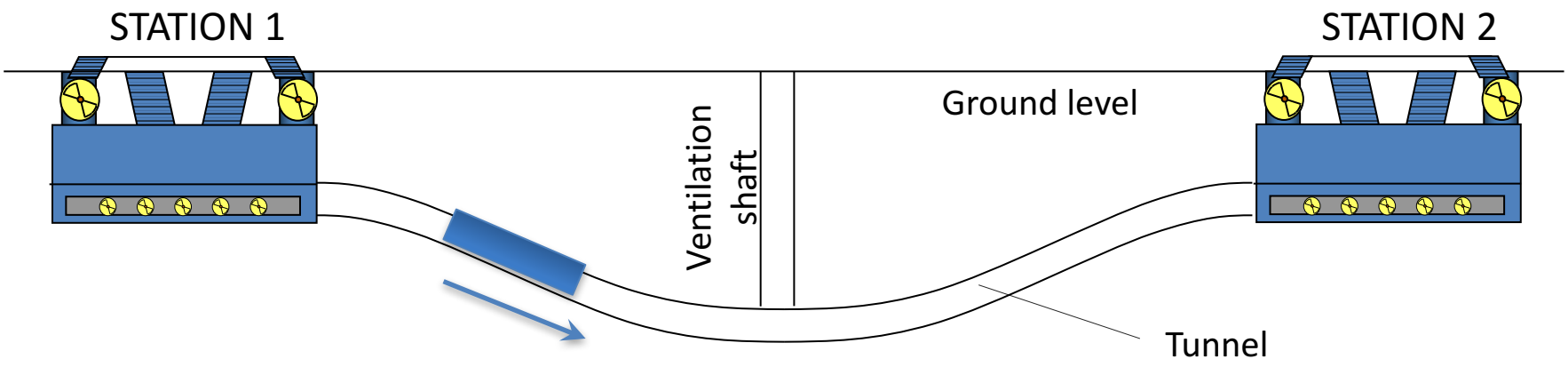
- Passengers waiting in each station platform are notified on the passenger loading of each of the cars of the next due to arrive.
- Hence passengers position themselves to enter the train cars with less passengers.
- This may save 2-3 seconds of dwell time per train per station, hence it minimizes the idle time of the trains and thus saves energy.

New tunnel ventilation scheme



- Normal train operation based on train piston effect
- Heat loads in tunnels are reduced due to the energy return mechanism
- Emergency ventilation using the typical air supply from one station and air extraction from the other station with any one fan out of operation
- Energy is saved because no other ventilation systems operate to extract heat from stations or tunnels as in all past Athens metro projects

Humped profile in the tunnel vertical alignment



- Tunnel vertical alignment between stations is made with a local minimum elevation wherever possible
- This acts by gravity assisting train acceleration when leaving a station and also assisting train deceleration when arriving at a station.
- The above geometry saves 5-8 % of the total traction energy, while it also minimizes the wear on the brakes.
- Detailed investigation shows that a 2.5 % vertical gradient is the optimum one in balancing the energy operational – cost benefit versus the additional capital cost of a deeper tunnel needing a pumping facility at its lowest point.

Use of LED lighting and advanced lighting control techniques

- All lights in Line 4 station public areas, staff areas, tunnels, shafts, maintenance areas and depot buildings shall use LED lighting.
- LED lights are expected to :
  - Reduce the lighting energy consumption by approximately 60%
  - Reduce the lighting maintenance cost by approximately 65%. This is very important as maintenance in stations and tunnels can only be performed at night hours and at a high cost
  - Increase the lifetime of the lighting fixtures to >30.000hrs.
- The above power reduction reduces accordingly the cables, the circuit breakers, the UPS sizes and the batteries supporting the normal and emergency lighting systems
- LED lights may provide a strong tool for installing architectural lighting in stations, improving the overall aesthetics.
- Carefully engineered lighting circuits, using sensors, dimming and low lighting levels when not required (eg certain periods during night hours) are expected to minimize the lighting energy consumption.

SCADA and Systems Automations

The SCADA / Control Systems below, monitor and control the 55 electromechanical and railway systems of Line 4. They have been developed with specialized energy saving software in the operational profiles, and they are categorized as follows :

- BACS (Building Automation Control System) monitors and controls the mechanical and building facility installations (Tunnel Ventilation, HVAC, Lifts, Escalators, Pumps, Fire Fighting, Lighting, etc)
- PRCS (Power Remote Control System) monitors & controls the electrical systems (Medium Voltage – 20 kV, Traction power and its subsystems, Power Distribution)
- ICMS (Integrated Communications Management System) monitors & controls the Low Voltage systems (CCTV, Public Address, Clocks, Data Transmission, Telecoms, Access Control and Security Systems, etc)
- ATC-ATS (Automatic Train Control – Automatic Train Supervision) monitors & controls the movement of the driverless trains

Besides the above, certain systems have built-in energy saving functions. Typical examples are escalators and travellators stopping their operation at no load (ie when no passengers are present).

Conditioned Based Maintenance

- Trains and systems maintenance will be organized using Condition Based Maintenance with on-line information coming from sensors installed in critical systems and subsystems, in turn feeding PLCs and computers monitoring their operation and warning the maintenance staff accordingly through expert software systems installed in servers.
- Four families of systems (Mechanical, Electrical - Power Supply, Electrical – Low Voltage and Rolling Stock) will each have their on-line own Data Warehouse, storing all systems and subsystems faults, alarms, malfunctions and failures and thus assisting in maintenance projection and planning.
- Sensors shall include vibration sensors - accelerometers (in 1D or 3D), temperature sensors, pressure sensors, noise sensors, light sensors, various electrical sensors, etc.
- In actual practice this is expected to :
  - reduce maintenance activities initially by 15 %, in the long run by 35%
  - optimize the planning, acquisition and use of spare parts
  - save energy & operational cost due to reduced maintenance activities

Other classic energy saving schemes

Cosine correction in power substations

Every Lighting and Auxiliaries Substation (LAS) is equipped with banks of capacitors that apply load compensation and improve the cosine factor in the electrical installations to approximately 90%. This results in savings of the order of 5-6% in the base lads electrical loads (fans, HVAC units, lifts, elevators, pumps, lighting, etc).

Use of high efficiency motors

Throughout the Line 4 project, high efficiency electric motors will be used in all sizes of fans, chillers, air handling units, heat pumps, rainwater and sewage pumps, escalator and lift motors, fare collection gates, Platform Screen Doors motors as well as motors in maintenance equipment. All the above types of motors should comply with the EU directive 640/2009 on motor efficiencies.

Minimizing the Carbon Footprint

The Carbon Footprint of the Line 4 project has two components :

A. Carbon Footprint during construction, which includes the following directions :

- Do not overdesign the functional areas of all the structures, mainly the stations
- Do not overdesign the civil works and concrete structures
- Utilize materials manufactured/produced at the closest possible distance (e.g. use marble tiles from a local quarry rather than granite tiles from a quarry in East Asia)
- Use of recyclable materials wherever possible in stations, tunnels, trains and systems
- Minimize the transportation activities during construction (eg soil dumping, bringing to the sites the TBM concrete segments, bringing the concrete from nearby concrete plants, etc)

B. Carbon Footprint during operation which includes the following practices :

- Energy consumption minimization through systems efficient operation
- Traction energy regeneration and return maximization through special schemes
- Maximizing of systems life duration and systems recycling when their life is over.
- Minimizing maintenance activities through Condition Based Maintenance

CONCLUSIONS

- Advance energy saving and energy optimization concepts and schemes are designed and specified for implementation for the new 12.9 km Metro Line 4 in Athens with 15 new stations and 20 driverless trains.
- These include :
  - Traction energy consumption minimization techniques for the movement of trains through optimizing the train fleet movements via the signaling system
  - Traction energy return scheme at the traction substations, from the train braking back to the city 20 kV Medium Voltage network.
- Energy saving measures related to passengers include :
  - Assisting the train headways selection (eg a train every 2 minutes) as based on the actual on-line passengers data collected by the fare collection systems
  - Automatic passengers train loading information at each station on each of the cars of the next arriving trains, thus reducing the trains idle time.
- A new tunnel ventilation scheme, the tunnel vertical profile alignment with local minimum elevations, LED lighting, power compensation and cosine correction factors in the power substations, SCADA & systems automations, use of high efficiency motors and Condition Based Maintenance are also planned to be implemented under the principles of maximized energy saving.
- The above reduce the Carbon Footprint both during construction and during operation, throughout the life cycle of the project.

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