State-of-the-Art in Light Rail Alternative Power Supplies

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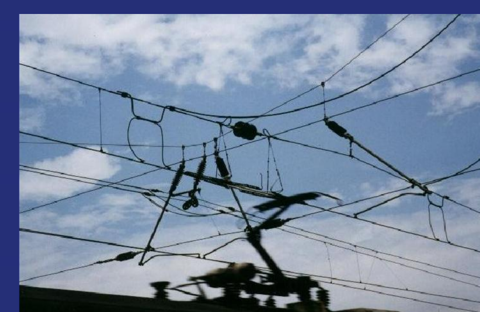
Background

- Conventional OCS preferred power distribution since 1880s
- Complex subject best approached from a *systems* viewpoint
- Three basic types:
  - Ground Level Power Supply (GLPS)
  - Onboard Energy Storage System (OESS)
  - Onboard Power Generation System (OPGS)
- Plus hybridized combinations!

Advantages

- Improved aesthetics
- Reduction in conflicts with other users of the street space
- Potential for infrastructure simplification



Disadvantages

- Vehicle becomes more complicated; weight, space and performance trade-offs
- Onboard Energy Storage- unknown life expectancy of energy storage elements
- Ground Level Power- high cost / proprietary, complicates infrastructure
- Onboard Power Generation- hydrogen technology not mature, expensive, requires fueling

Current Status Worldwide 1

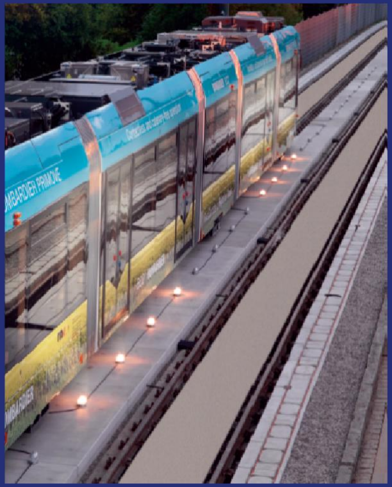
Ten years ago (2005): only one "off wire" system in commercial service (Bordeaux, using GLPS)

Rapidly changing - today there are:

- **8 systems using Ground Level power supply with 5 more under construction**
- **9 systems using Onboard Energy Storage for off-wire with 8 more under construction**

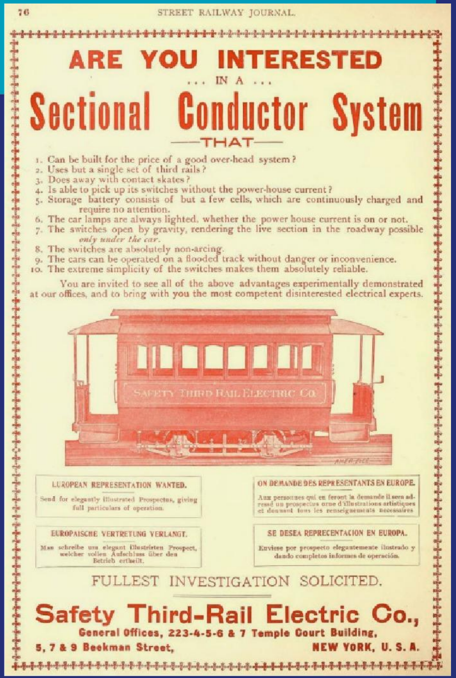
Current Status Worldwide 2

- 4 systems using Onboard Power Generation with one under construction
- Numerous systems using energy storage to achieve energy savings
- More than 27 development prototypes in last ten years!



Technology Evolution

- Automotive sector driving development of energy storage devices
- Battery, Super Capacitor, Flywheel and Fuel Cell technologies advanced considerably in last decade
- Light rail / streetcar / tramway vehicles ideal candidate for application of OESS
- Market factors slowing initial progress:
  - Low production quantities
  - Inherent conservatism of railcar market, where 30 year vehicle life is norm



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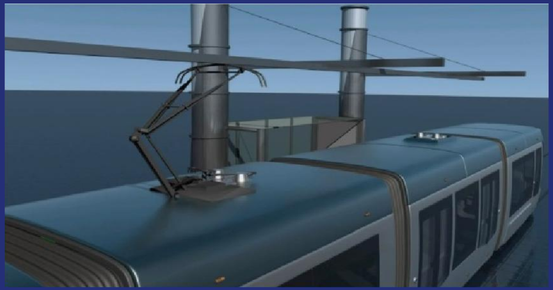
Evolution- Ground Level Power Supply

- **Initial approach was to provide a continuous power supply**
  - **Advantageous where HVAC requirements are high, steep uphill gradients, etc.**
  - **Downside: complex ground level infrastructure is high cost / proprietary**
- **Hybridized concept with more onboard energy storage reduces ground level infrastructure (e.g. only at stops and uphill segments)**

Evolution- Onboard Energy Storage

- OESS is a non-continuous power source (requires recharging enroute)
- Charging method depends on system design-
  - Charging while under wire (for short off-wire segments)
  - “Charging station” at stops (for longer distances – ground level or overhead pick-up)
- Length of “off-wire” segments increasing on new systems
- Continuing evolution / improvement of energy storage elements



Evolution- Onboard Power Generation

- Slowest to develop due to space impacts, periodic refueling and other trade-offs
- Diesel hybrid tram-train applications
- Major hydrogen fuel cell advances on the horizon, but costs still high

Conclusions 1

- Alternative power supplies entering new phase of development; large number of "early adopter" systems now coming on line – more coming
- Energy storage devices evolving rapidly, driven by automotive sector
- Application remains very project-specific

Conclusions 2

- Commercial issues are significant
  - Little unbiased hard cost / reliability data available
  - Proprietary technology issues remain with GLPS
  - Initial and life-cycle costs still high
  - Are some solutions better suited to alternate project delivery methods?
- OESS has multiple uses – off-wire operation and energy saving (peak shaving)
- Emerging trend is OESS with periodic recharging

Parting Thoughts

- What industry R&D process changes could further speed up / improve development?
- What design and analysis tools are needed to analyze system requirements, optimize design and size vehicle OESS?
- How are standards (or lack thereof) impacting development? What new standards is the industry already working on?
- How are operational impacts being considered? (transit not known for babying equipment)
- What about specifying a vehicle capable of future off-wire upgrade?
- What is the optimal design for charging points and associated equipment?
  - Current collector up/down automation
  - Power supply/distribution to charging points