Energy consumption reduction in urban rail systems

Plan of the presentation

- Introducing the speaker and transport-related research at her university
- Urban rail transport in Poland - a very short overview
- Urban rail transport oriented research - centres, areas of interest, overview of projects
- Relevance of ongoing research to Sustainable Surface Transport Call within FP7 Transport Theme

Speaker and her university

Dr. Barbara Kulesz, currently employed at Silesian University of Technology, one of Polish technical universities. At present with the Department of Electrical Machines and Electrical Engineering in Transport, which is situated within Faculty of Electrical Engineering.

Research scope and potential of my home unit

In the past:

- supply systems of railway traction (with stress laid on the issues of re-adjustment of peak loads at railway traction substations with the help of energy storage systems; a Ph.D. thesis may be mentioned here)
- hybrid locomotives design (again, problems solved here related to determination of diesel shunting locomotives loads and possibilities of transforming them into hybrid, i.e. diesel-electric locomotives; a doctoral thesis must be recalled here)
- rail vehicles drive systems (in particular, research has been aimed at design of new types of electric motors, such as induction motors and PM excited motors, which would be swapped for today's standard dc motors)
- rail vehicles static converters (used to drive fans cooling electric motors).

My own field, for several years past, has been design and operation of multi-phase transformers for urban rail vehicles (mostly trams) traction substations. It covers issues such as quality of rectified voltage and impact of different types of transformer-rectifier sets on the supply grid.

Nowadays our principal field of interest is associated with cars and includes:

- car electronics (motor control systems – ignition, injection)
- hybrid vehicles (cars and buses; algorithms for controlling diesel/electric drive – a very recent Ph.D. thesis)
- electric energy storage systems (batteries and super-capacitors) used in conjunction with hybrid drive for car or bus
- module hybrid drive system.

Research example - Module hybrid drive system

Module drive system is defined here as system which may be built into existing car IC motor without introducing any major constructional changes. This will operate in a manner similar to known hybrid drives. The proposed drive system will consist of electric machine acting as alternator, starter and auxiliary machine (this last function means generation of torque which adds to IC motor torque, e.g. during acceleration). During frequent stops the IC motor will be switched off, which will reduce both fuel consumption as well as noise and environmental pollution (CO_2 mostly). Electric motor supply will be run from super-capacitors via power electronics converter.

Within the framework of the project we intend to:

- Design and build a small but high-power electric PM motor
- Design and build power electronics converter with control module
- Assembly mechanical transmission connecting electric machine to belt pulley of car engine shaft
- Put a super-capacitor battery into the system.

Automatic switching off of IC motor, repeated switching on of drive motor (the IC motor start-up will be done with the help of electric motor operating as a starter)

Recuperation of energy and charging batteries and super-capacitors. In this case electric machine will operate as alternator and be controlled in such a way as to provide fast supply of energy to charge the storage elements or to recover a part of braking energy. The electric machine will also operate as alternator in order to lower the load of IC engine (power to car lights, board appliances, IC engine ECU unit, ignition and injection systems, fuel pump will be taken from energy accumulators)

Storage of energy in double accumulator (VRLA battery and super-capacitor bank). Super-capacitors will be used to provide starting energy to IC engine during repeated start-ups in urban communication.

This system will be better than known existing hybrid drive systems or Stop and Go systems, since relatively cheap and mass-produced elements will be used. Its efficiency will be much higher than in case of known Stop and Go systems (electric PM motor with 94% efficiency as opposed to standard toothed rotor alternator with 50-60% efficiency); its power will be also several times higher.

Thanks to this power it will be possible to fulfil three designed functions:

Braking energy regeneration

Start-up in electric mode

Instantaneous assistance of IC engine.

Together, these are seen as a novel solution of the old problem: decrease of fuel consumption and pollutants emission.

Our research infrastructure

In the field of electric traction:

- electric motors, dc, ac, PM
- power electronic converters
- laboratory test stands with traction transformers-rectifier sets models

In the field of hybrid/electric vehicle technology:

- two electric vehicles (one fully registered and certified for road traffic), the third is currently being built
- one of the above is also configured as hybrid car with series structure

Measurement equipment:

- Car diagnoscopes (Bosch, ADP), fully legalised
- Multi-channel oscilloscopes Tektronix
- Signal recorders (RCUF) used in road measurements
- Exhaust gas analyser MAHA
- IC engine with control module (laboratory stand)
- Thermovision equipment (FLIR camera)

Urban rail transport in Poland

Trams – 14 cities, Metro – 1 city, Trolleybuses – 3 cities

Rolling stock manufacturers (home and abroad): Alstom Chorzów,FPS Poznań, Pesa Bydgoszcz, Bombardier, Siemens, Skoda

Rolling stock modernisation: Modetrans Poznań, Protram Wrocław

Together: 80 different types of tram cars

As of 2009: 3669 trams, 85% of them with series-shunt dc drive

Average energy consumption for standard(“classical”drive) - >=2.1kWh/km/one 105Na car
For asynchronous drive – 1.7kWh/km

Energy save – c.19% (resistor losses during start-up are eliminated, asynchronous motor with higher efficiency – c. 5%, limiting resistor losses during braking, exchange of rotating voltage converter with static one).

Additionally – fewer contact-type equipment, lower maintenance costs, lower failure frequency

Example of urban transport network – GOP (Upper Silesia industrial region)

Buses (one principal operator, several small operators)
Private transport (minibuses)
Rail transport: Trams, railway, trolleybuses

300 bus lines, 29 tram lines, 1.2 mln persons/day

Rail transport:
Tram lines 210 km and 338 stops, 12 cities
Railways 180 km, 55 stations, different lines

Integration: buses and trams only

Rolling stock: 5% of tram cars < 5 years
57% of tram cars – between 20 and 30 years

Modern trams (with energy recuperation, low floors) – 24 trams out of 346 (2009)

Trolleybuses (one town) – 6 cars with energy recuperation (out of 21),
1.2 mln km per year

Transport policy for cities and agglomerations for 2007-2013

- Strategy of State Development 2007-2015
- National Strategy Framework 2007-2013 (Coherence National Strategy)
- Operational Programme “Infrastructure and Environment” – 37.6B euro, EU contribution 27.9B euro (19B – development of transport infrastructure, 5B – environmental protection, 1.7B – power engineering)

Research under FP7 Call: “Transport”, “Sustainable Surface Transport” points out following possible areas of improvement:

•new rolling stock – smart energy management and recovery technologies
•existing rolling stock – to be retrofitted in order to benefit from recuperative braking

Research objective – to reduce energy taken by urban rail systems by 10% by 2020

Apart from rolling stock, solutions should also be aimed at heat dissipation in tunnels, stations and rolling stock;energy storage and reuse of energy by means of on-board equipment or station/wayside appliances

Advanced technologies mentioned are:
Batteries, flywheels, super capacitors, reversible dc substations
Smart management of electricity

Attention should be paid to identifying of safety risks to customers and staff related to new technologies of energy storage

Research in Poland

- Several university centres, usually Faculties of Electrical Engineering and/or Transport
- Several R&D centres

Gdańsk University of Technology

- methods of determining load parameters in complex electrotractive systems
- investigation of traction drives with synchronous motors and sensorless control
- investigation of noise sources in trams
- identification of components generated by dc/dc converters
- recuperation of energy in trolleybuses

Railway Institute, Warsaw

Principal Polish R&D centre, cooperating with UIC, OSŻD, SCIRO TUV, RINA SpA, TUV NORD, TUV SUD, NB Rail

- rolling stock testing (elements, sub-assemblies) – urban vehicles, railways
- rail tracks testing
- supply testing (traction and power grid)
- traffic control appliances testing
- rolling stock and infrastructure material and elements testing
- experimental track investigations

Electrotechnical Institute, Warsaw

- DC traction supply systems
- New type of high power traction drives
- Hybrid supply systems for vehicles and traction network
- On-board power electronic static converters for rail vehicles
- Control systems for traction vehicles

Current research and development projects (financed by Polish Ministries):

- Polish-Russian cooperation – Elaboration of modernised super-capacitors with more simple design and cheaper manufacturing processes
- Advanced methods and manufacturing processes for energy storage elements such as super-capacitors, fuel cells and hydrogen tanks (under COST/261/2006, duration 2007-2010)
- High Performance Energy Storages forMobile and Stationary Applications (under COST Action 542, duration 2006-2010)
- Capacitor storage elements (under COST 260, duration 2006-2009)
- Active filter of short and long-term power grid voltage decays with energy storage made of high-voltage super-capacitor components (under COST 255/06, duration 2006-2009)

Poznań University of Technology

Research centred on control algorithtms associated with energy saving drive styles in rail vehicles

Warsaw University of Technology

Recuperative braking of rail vehicles

Simulation of drive systems of EM units

Energy storage elements - batteries and super capacitors operating with 116N tram

Trolleybuses with capacitative energy storage on board

Example of research project

Trolleybus with transistor control system making possible effective use (90% efficiency) of energy supplied from substation, partial recovery of vehicle’s kinetic energy during braking.
Theoretically in urban traction it is possible to recover from 20 to 40% of energy supplied during ride and start-up – depending on traffic density, average speed and supply system structure.
That is *c*. 40MWh per year per tram.
In a medium-sized city, 400 trams, 16000 MWh per year.

Effective recuperation – depends on presence of other vehicles within the supply region.

In Warsaw 20% of trams is equipped with circuits making it possible to recover braking energy, but effective recuperation does not exceed 25% energy supplied for riding. If percentage of trams with possible recuperation goes higher, the effective recuperation will decrease.

Other possibility: super-capacitor storage
Investigation for trolleybus:
Energy save – 30 to 35% (depending on driving style, land conditions, current switches) and 10-15% increase in relation to vehicle equipped with energy recovery circuit (network) only.

Cracow University of Technology

- Electromagnetic compatibility (in electric traction)
- Power electronic converters for dual-system rail vehicles

Radom University of Technology

- Energy-saving systems in rail transport

Łódź University of Technology

Usage of super-capacitor energy storage elements in trams

Summary of latest research – assessment of cost effectiveness of using capacitor storage for two different substation region during and outside peak hours

	Substation I		Substation II	
	During peak hours	Outside peak hours	During peak hours	Outside peak hours
Recuperation into the network P_{av} in kW	77.2	81	111	115
Recuperation into supercapacitor	68.3	68.8	96.2	95.6
Difference	8.9	12.3	14.9	19.4
Annual gain in MWh	35.24	48.6	59	76.8
Annual gain in PLN	9867	13636	16520	21510

Energy storage 54F, U_{max}=400V, U_{min}=200V, W=0.9kWh
Storage cost – c.120000 PLN +
Chopper cost – c.30000 PLN
Total 150000PLN

Life time – c. 10^6 cycles (at U_{end}=1/2 U_N), hence 8.3 years
Average cost reduction due to energy reduction – 15000 PLN,
in 8 years 125000 PLN < supercapacitor cost

Conclusions

Modernisation of existing rolling stock and buying of new rolling stock with in-built energy recovery circuits - under way, managed by urban rail transport operators

Research on energy storage appliances - under way in several centres, some EU projects

Research on energy control strategies - under way in several centres, national financing only