



International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium

Montreal, June 19-22, 2016

Design of a Modular Swift-shift Multi-Speed Transmission with Double Dual-clutches for Electric Vehicles



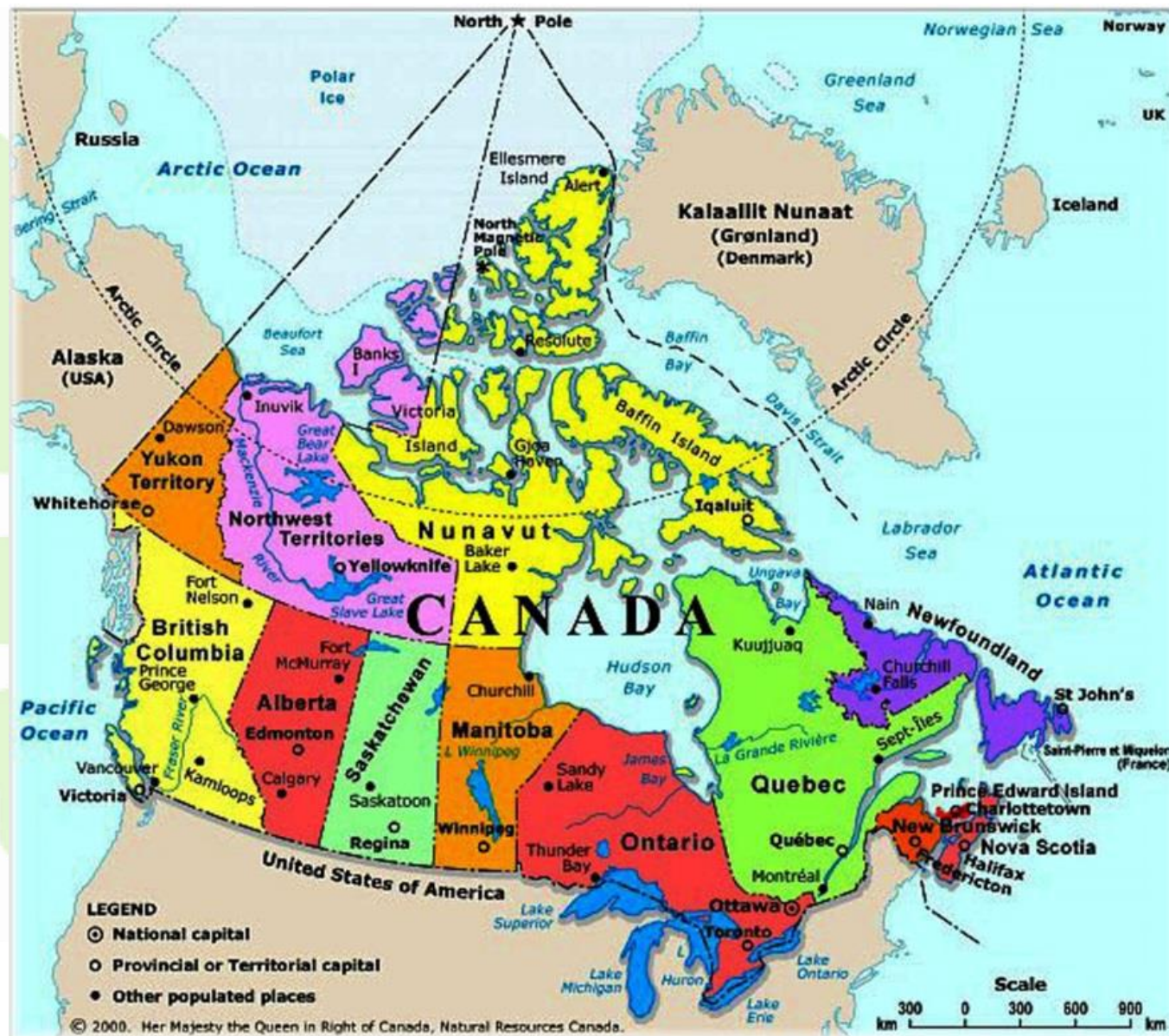
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Jorge Angeles, and Benoit Boulet*

McGill University, Montreal, Canada

Why is Quebec the right place for EV technology development?

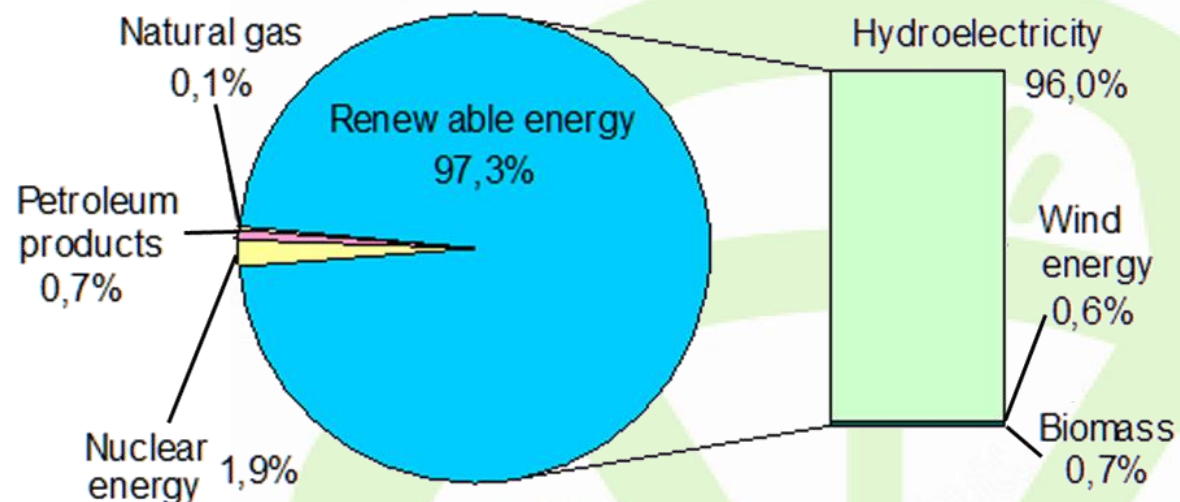
Hydro Québec:

- the largest electricity generator in Canada
- the world's largest hydroelectric producer



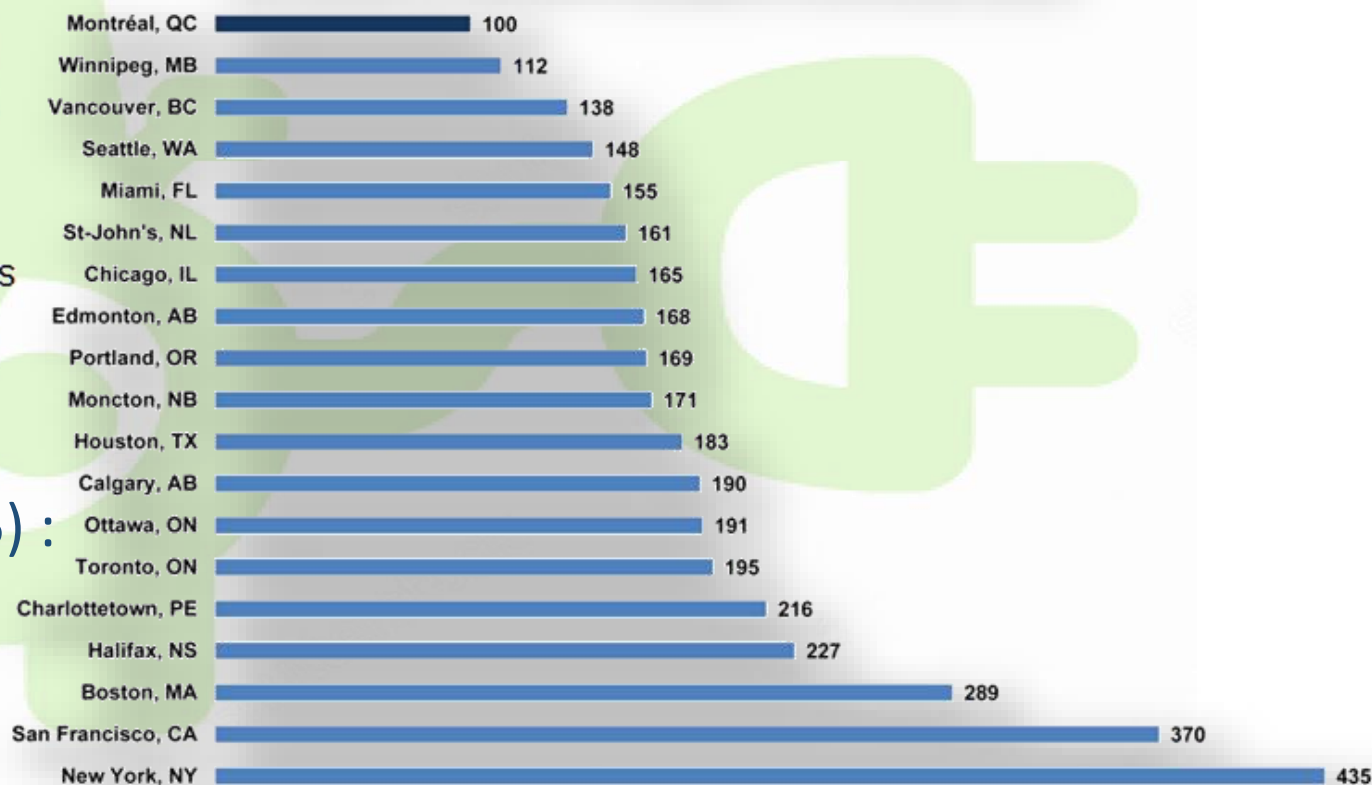
Québec & EV technology

Over 97% of Quebec's electricity comes from a renewable source



Comparative Index of Electricity Prices in 2014

Residential Customer Accounts at April 1, 2014 (Montréal = 100)
Index associated to a monthly bill for a consumption of 1,000 kWh (taxes excluded)



Ministère des Transports du Québec (2015) :

***Plan d'action en électrification
des transports 2015 > 2020***

Source: Hydro-Québec. Comparison of Electricity Prices in Major North American Cities. Rates in effect April 1, 2014.



Montreal & McGill University



Automotive Partnership Canada

McGill University Team

- Six professors
- 40+ HQP (research engineers, PDFs, Ph.D. and M.Eng. students)
- UG students (course and summer projects, extracurricular research)

Electric Drivetrain Design Team

- Analysis of two- and multi-speed transmissions for medium-duty BE commercial vehicles
- Design of a multi-speed transmission for e-trucks

Why multi-speed transmission?
Why transmission at all?



Automotive Partnership Canada

www.apc-pac.ca

Efficiency and transmission in EV

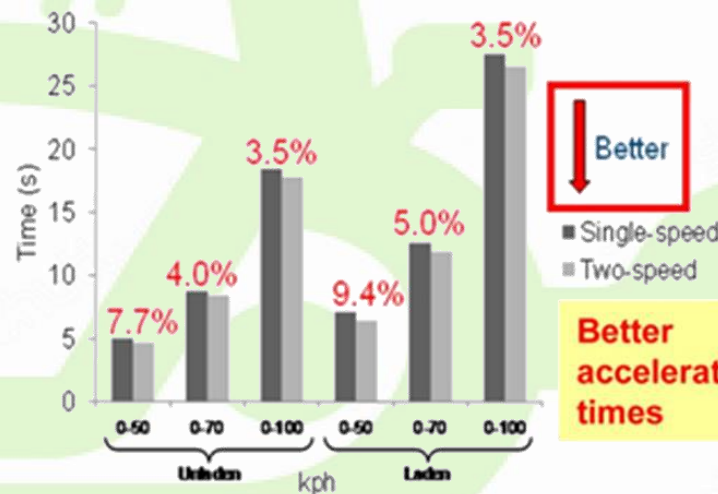


Study results for 2 speed

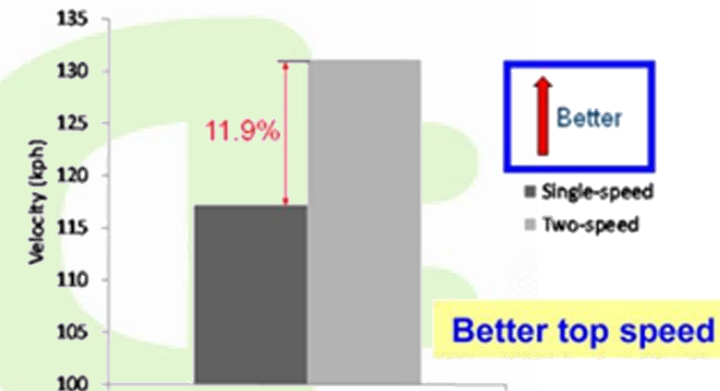
MOBIS
DRIVELINE CONTROLS

oerlikon
graziano

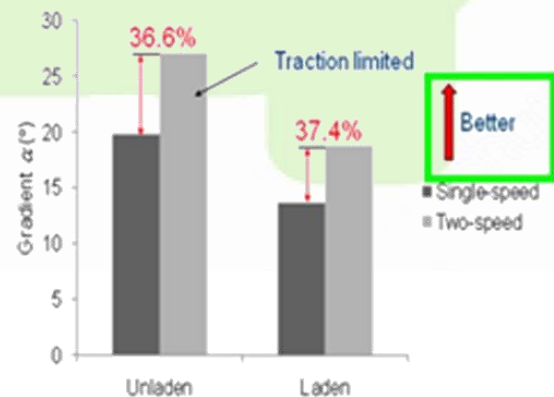
Case study was performed for twin speed in existing single speed E-Vito application.
In comparison to single-speed:



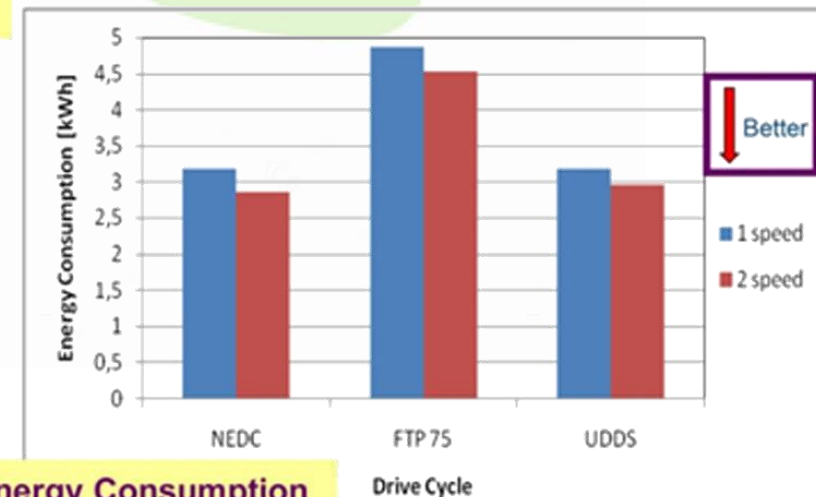
**Better
acceleration
times**



Better top speed



**Higher
ascendable
gradient**



Lower Energy Consumption

Analysis: 5-15% efficiency increment in small BEV with two-speed transmissions

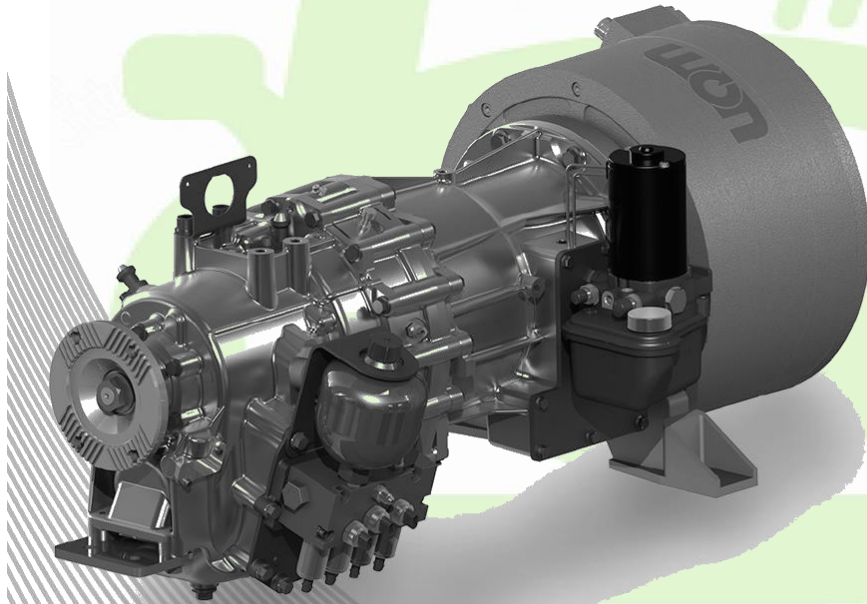
Two-speed vs single-speed EV

- acceleration
- top speed
- gradeability
- energy consumption

EV/MST in medium- duty trucks

Electric Vehicle International – Medium duty truck

Transmission: Two-speed Automatic Manual



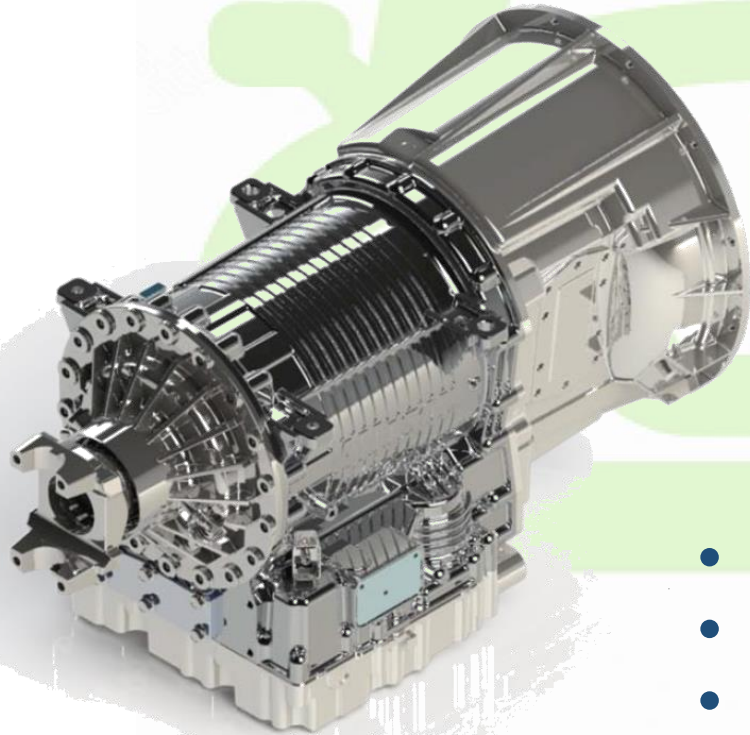
EV3-850 + PowerPhase HD 220

Kinetic Drive Solutions – Three-speed dual-clutch transmission integrated with the traction motor

EV/MST in medium-duty trucks

Balqon Corporation Nautilus XE-20

Six-speed fully automatic Alisson 3000 RDS



- standard four- and six-speed transmissions
- minimum modifications
- with torque converter

No research on the use of multi-speed transmission in electric trucks!

Development and optimization of a multi-speed transmission for e-truck

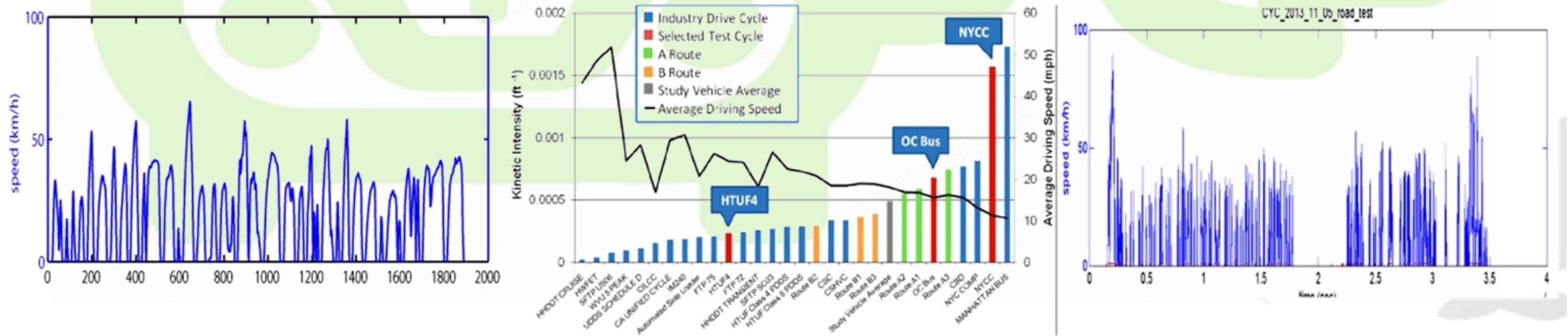
First phase of research: delivery van with two-speed transmission

- To develop a battery e-truck with two-speed transmission
- To compare performance/efficiency with direct-drive e-truck

Method: optimization via simulation

Prototype: 2004 GM Workhorse P32 chassis with Utilimaster body, fully loaded GVWR: 14,100 lb / 6396 kg

Drive cycle: Orange County Bus Cycle (OCC) Length: 10.53 km



Efficiency and performance of MST-EV for Class-4 e-truck



SUMO MD*

- Speed 0 – 3100 rpm
- Max power – 200 kW
- Max torque – 2100 Nm

Motive B** (scaled up)

- Speed 0 – 11500 rpm
- Max power – 200 kW
- Max torque – 343 Nm



Results

Energy consumption of two-speed E-truck is not as important as performance:

- » Top speed;
- » Acceleration time;
- » Gradeability

- * Connected directly to the final drive
- ** Connected via two-speed transmission

Our vision

In the nearest future:

Forthcoming breakthrough in battery technology:
reduction of

- weight,
- size,
- cost



significant increment of battery electric medium- and heavy-duty vehicles

The heavier the e-truck, the more important the use of MST will be

Our goal: development of a novel concept of multi-speed transmission for commercial electric vehicles

Novel concept of multi-speed transmission for EV

Modularity

- gear steps can be added at the design stage as needed, depending on the application;
- virtually any number of speeds can be added, both under-drive and over-drive.

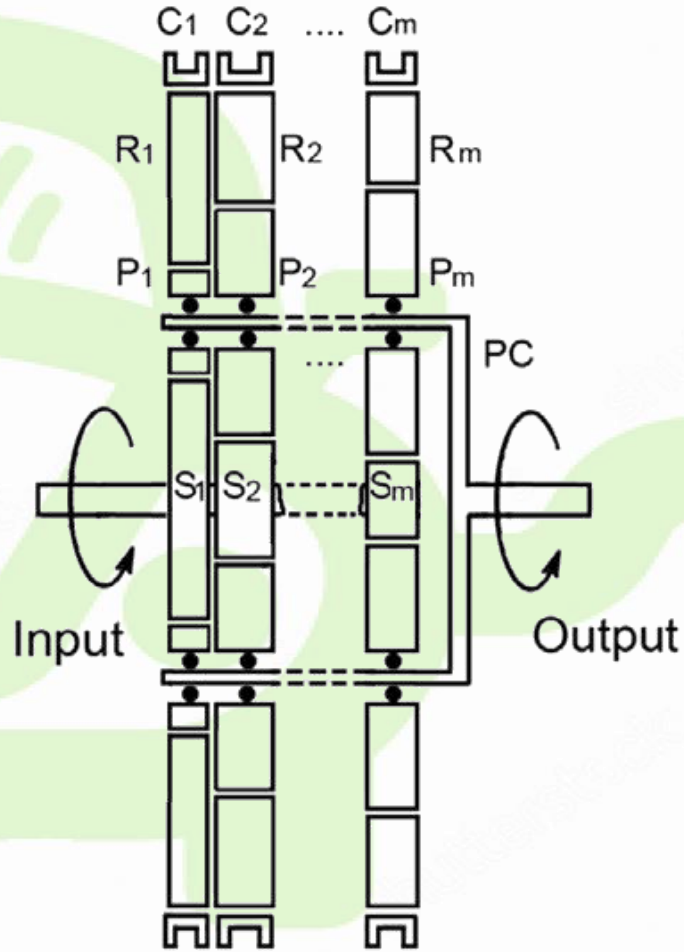
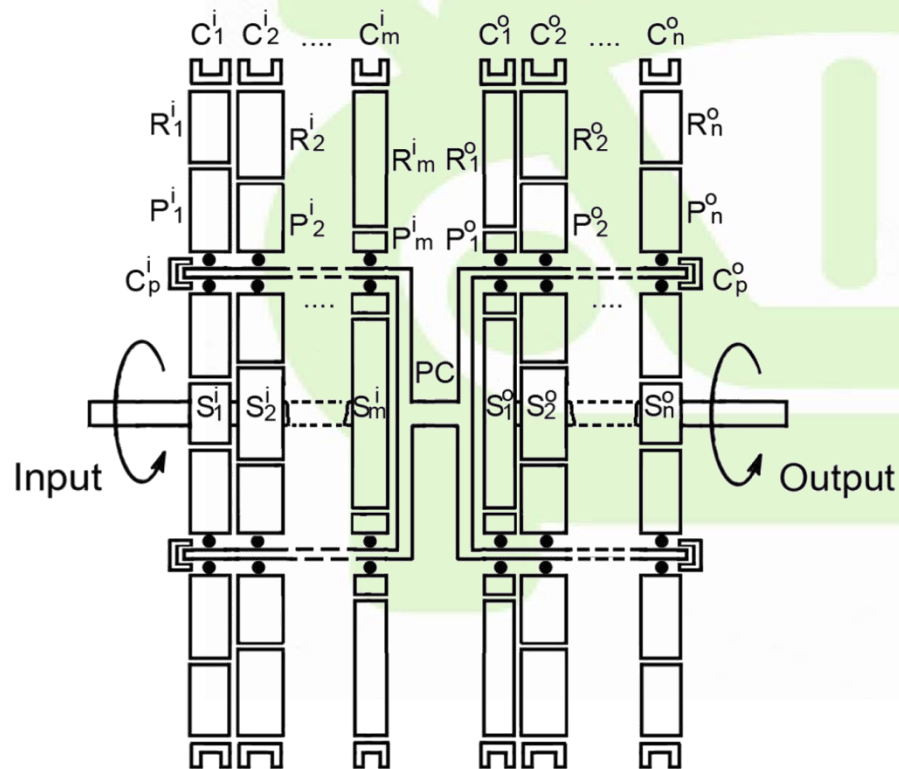
Simplicity

- no need of torque converter or clutch, since torque is generated by the traction motor from stall;
- no need of designated reverse speed gears.

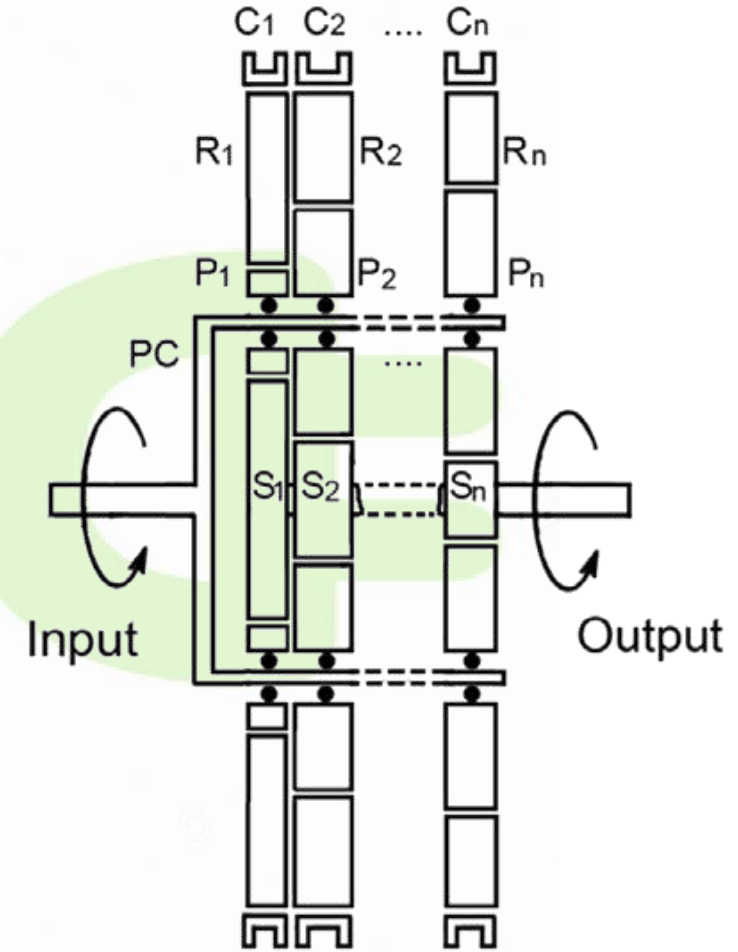
Novel concept of multi-speed transmission for EV

Different geartrains

- Under-drive speeds,
Ratio > 1.0
- Over-drive speeds,
Ratio < 1.0



a) Underdrive Geartrain



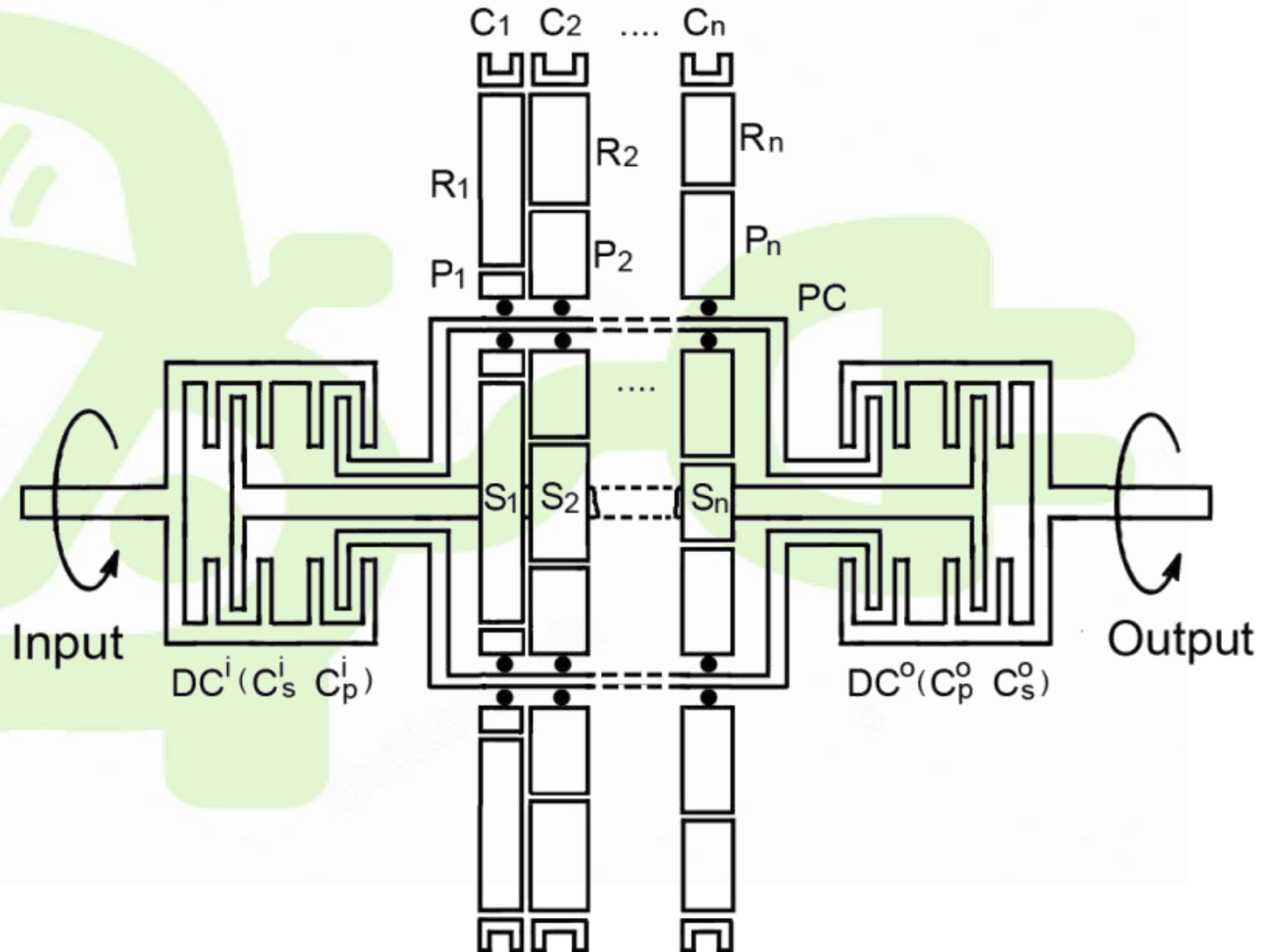
b) Overdrive Geartrain

Novel concept of multi-speed transmission with double dual-clutches for EV

Same geartrain

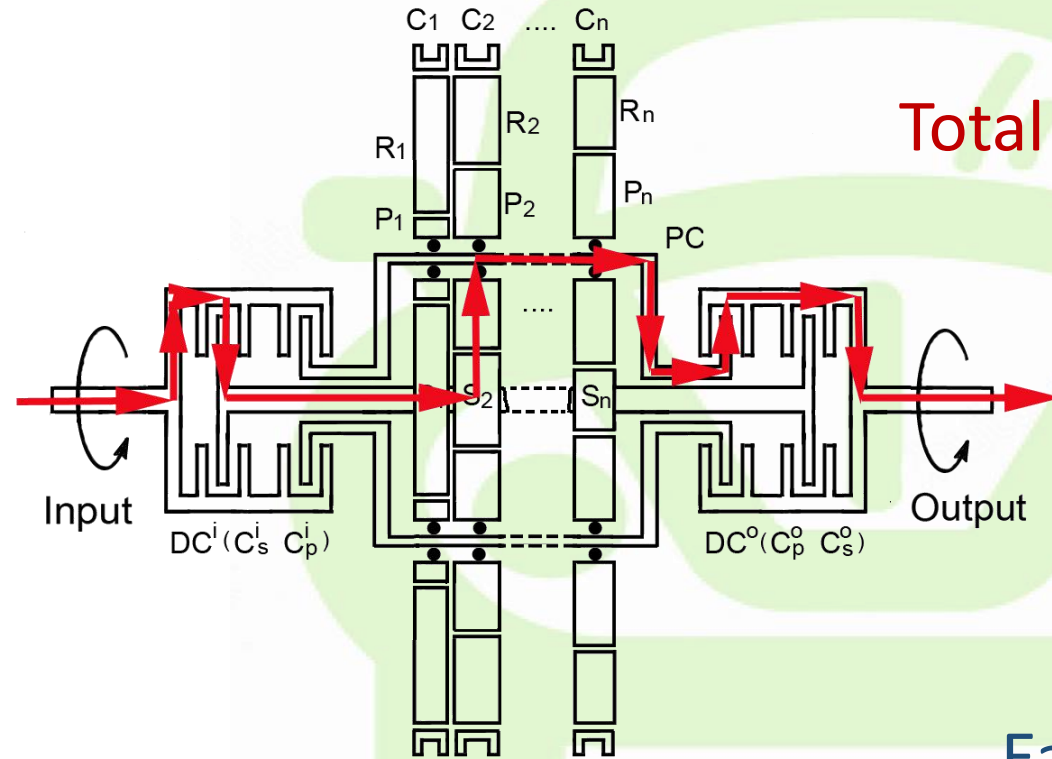
- Under-drive speeds,
Ratio > 1.0
- Over-drive speeds,
Ratio < 1.0

Reduced number of modules



Novel concept of multi-speed transmission with double dual-clutches for EV

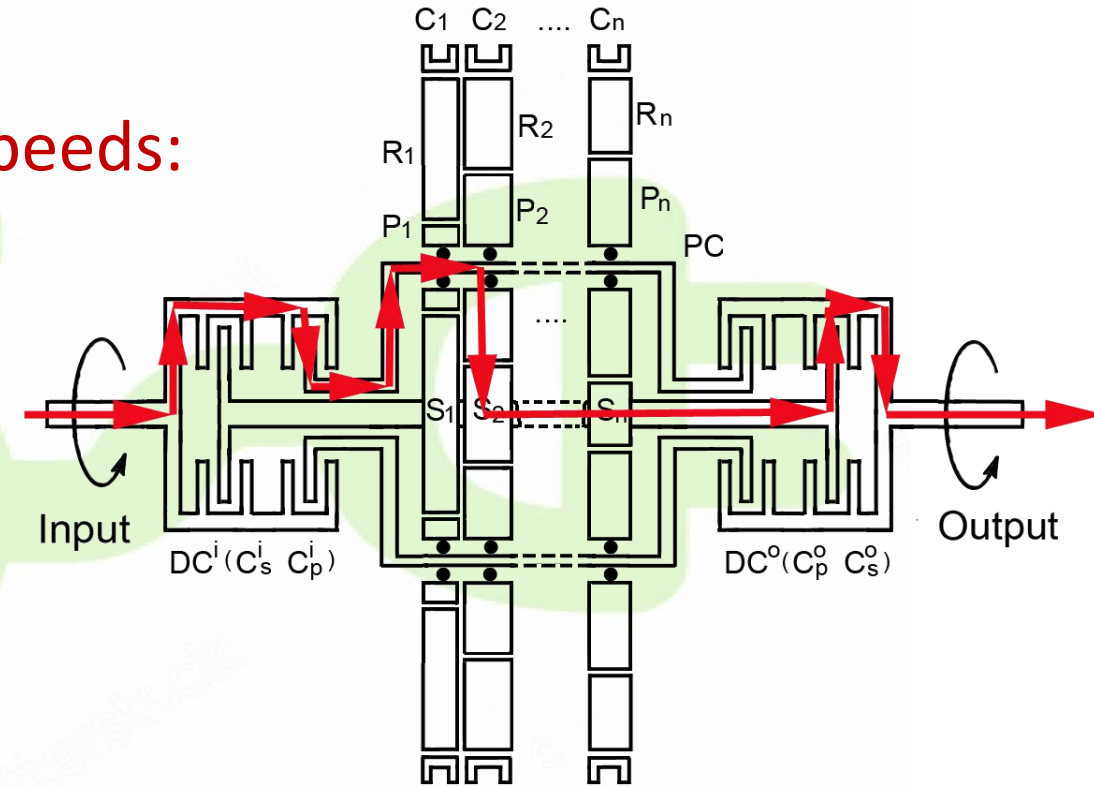
Main under-drive speeds



Total number of speeds:
 $k = 2n + 1$

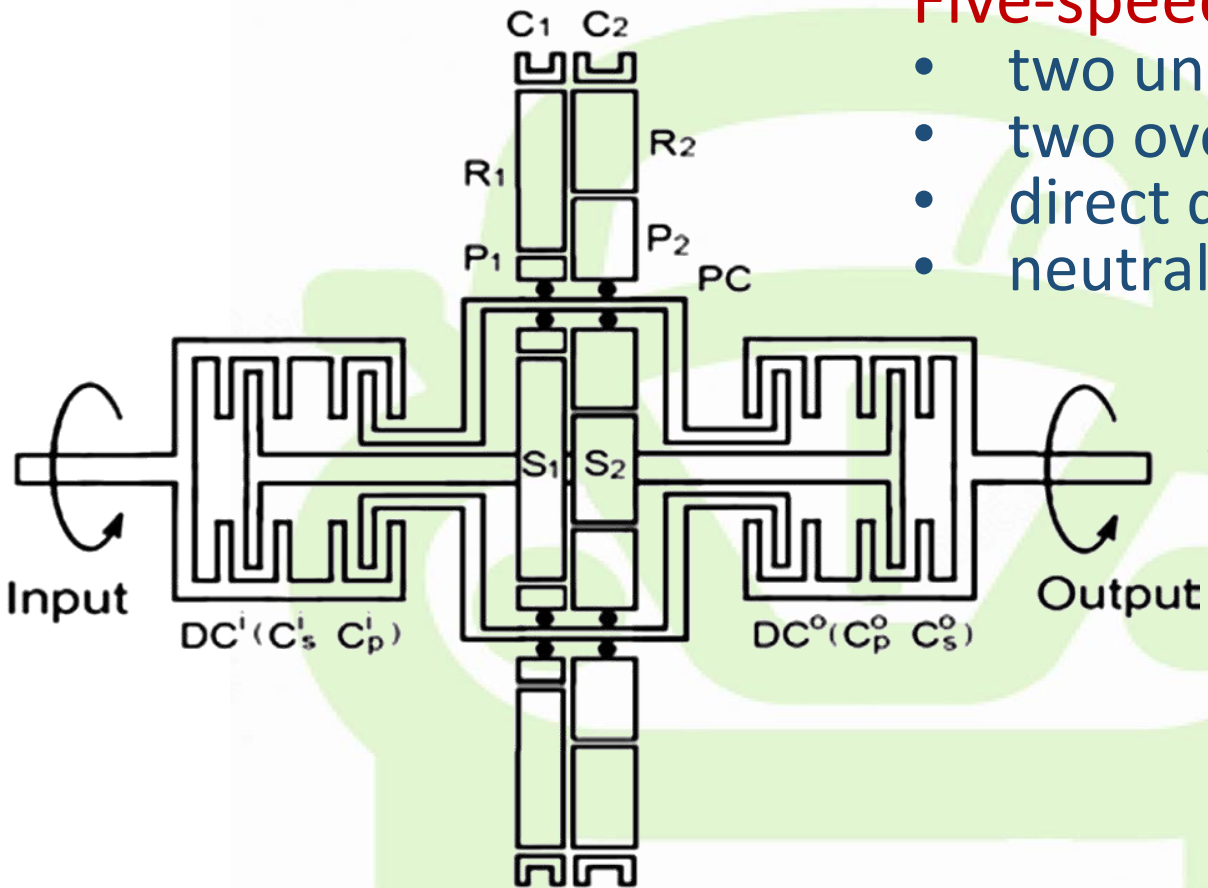
Each module

Main over-drive speeds



- produces both under-drive and over-drive speeds
- leads to smooth gear-shifting

Novel concept of multi-speed transmission with double dual-clutches for EV



Five-speed transmission

- two under-drive speeds;
- two over-drive speeds;
- direct drive;
- neutral.

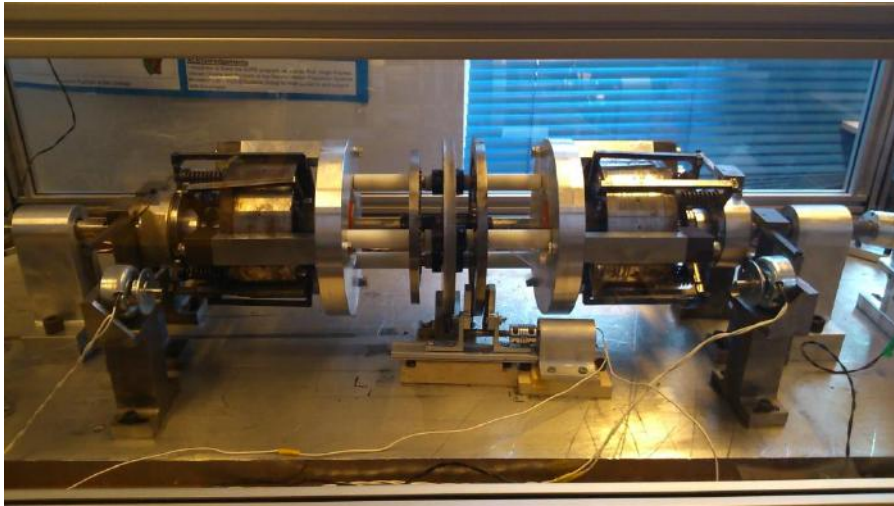
Symmetric

- Two under-drive PGS (4:1 & 2.67:1);
- Two over-drive PGS (1:4 & 1:2.67).

Table: Clutch schedule for five-speed transmission

Transmission state	Gear ratio	Clutch state					
		C_1	C_2	C_s^i	C_p^i	C_s^o	C_p^o
underdrive	4	1	0	1	0	0	1
underdrive	2.67	0	1	1	0	0	1
direct	1	0	0	1/0	0/1	1/0	0/1
overdrive	0.25	1	0	0	1	1	0
overdrive	0.3745	0	1	0	1	1	0
neutral	0	–	–	0	0	0	0

Work in Progress: Testbed Prototype & Simulink Model

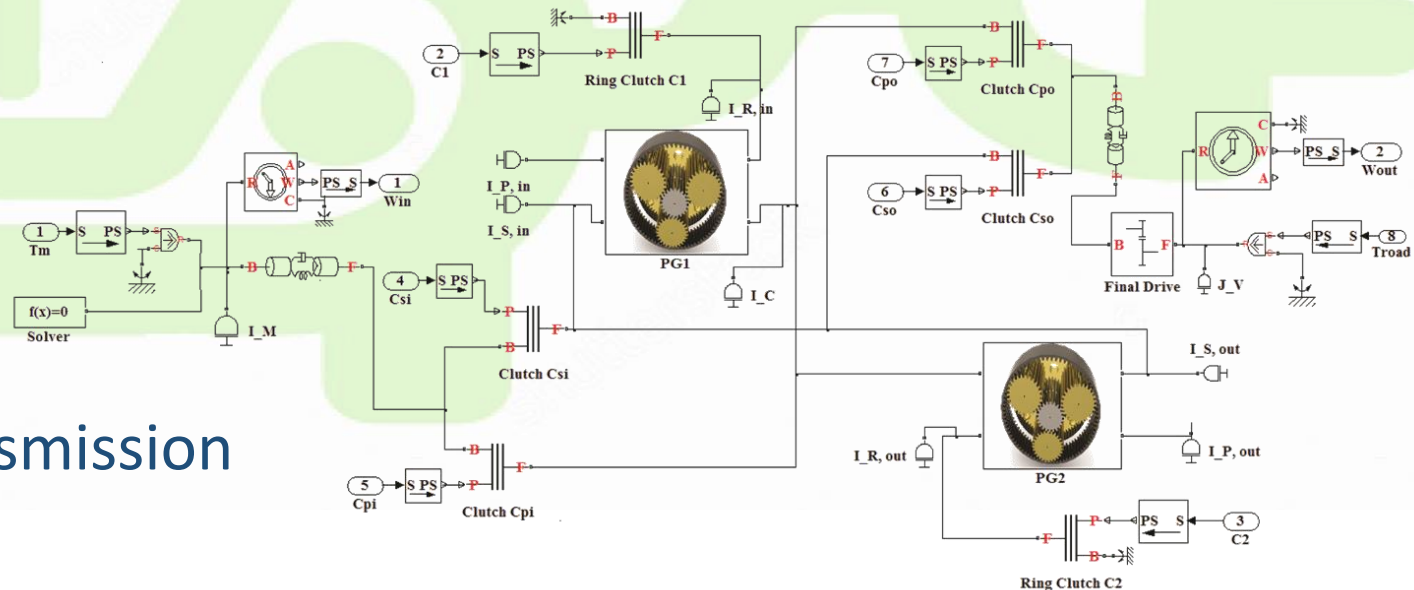


Five-speed Transmission Testbed

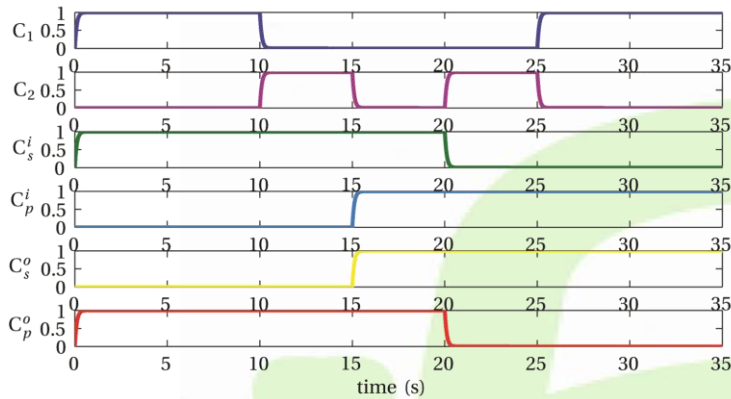


Dual-Clutch

Layout of the 5-speed transmission with double dual-clutch

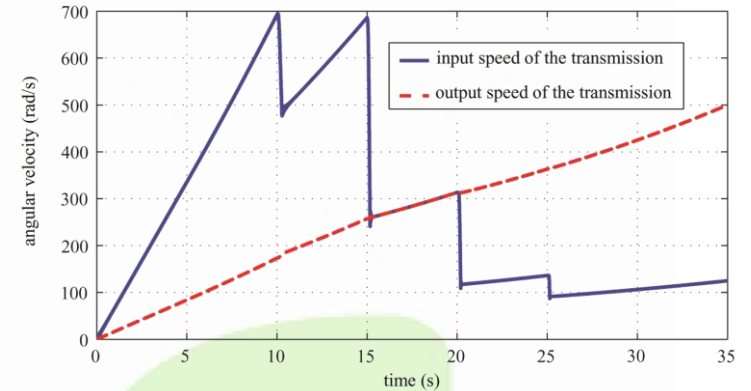
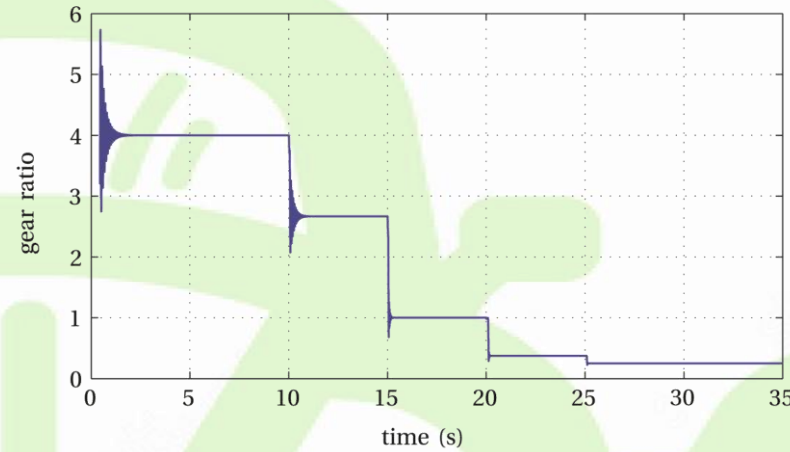


Preliminary Simulation : Constant Input Torque



Clutch pressure signals

Simulated gear ratios



Input and output angular velocities

Goal: control by speed (with default torque provided by preset current)

Vibration: No vehicle dynamics taken into account

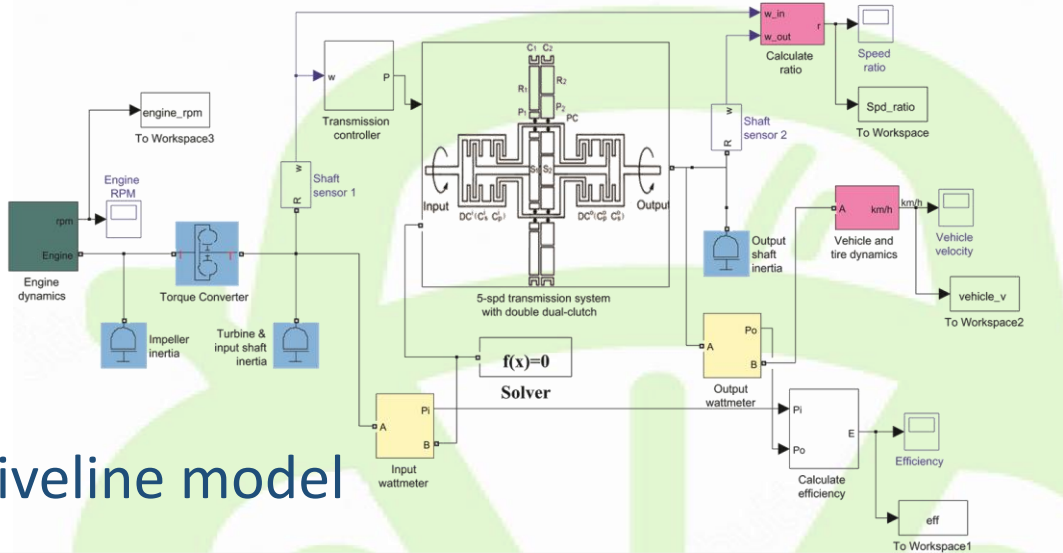
Task: simulation for actual driver's control with better driveability

Algorithm:

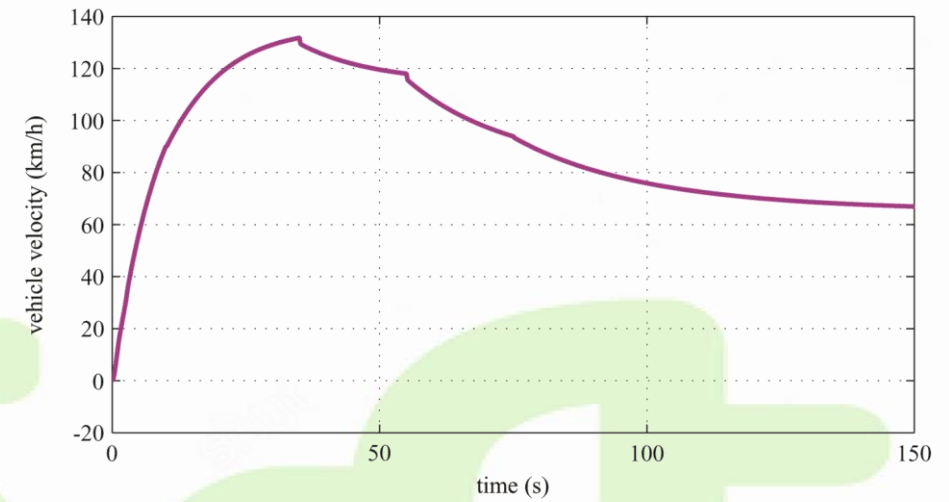
- Five-gear shifts
- Smooth shifting
- Swift-shifting

Preliminary Simulation : Transmission within Vehicle

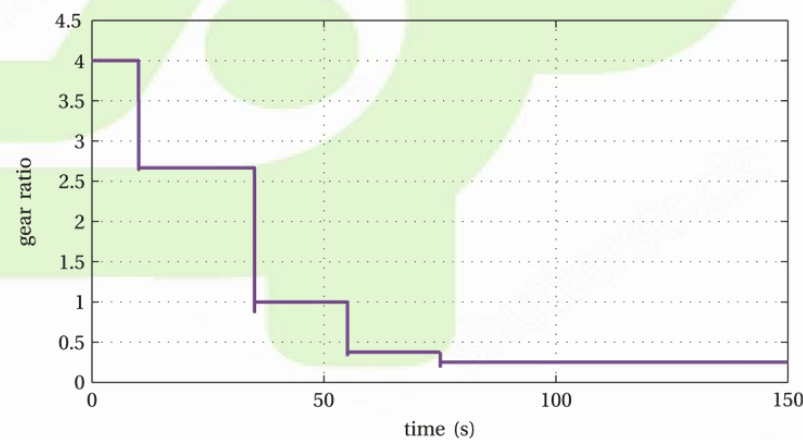
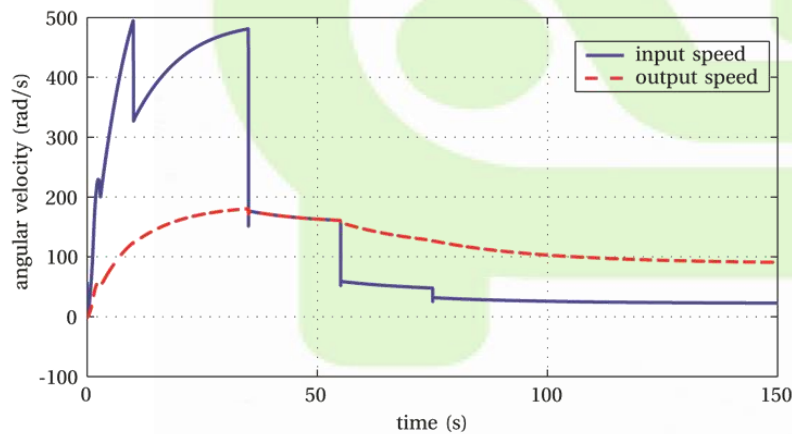
Step 1: Preprogrammed Clutch Schedule



SimDriveline model



Vehicle velocity

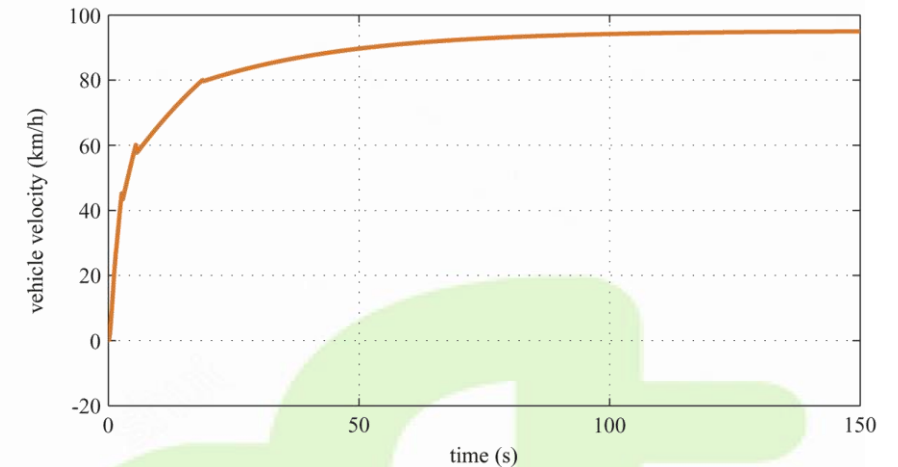
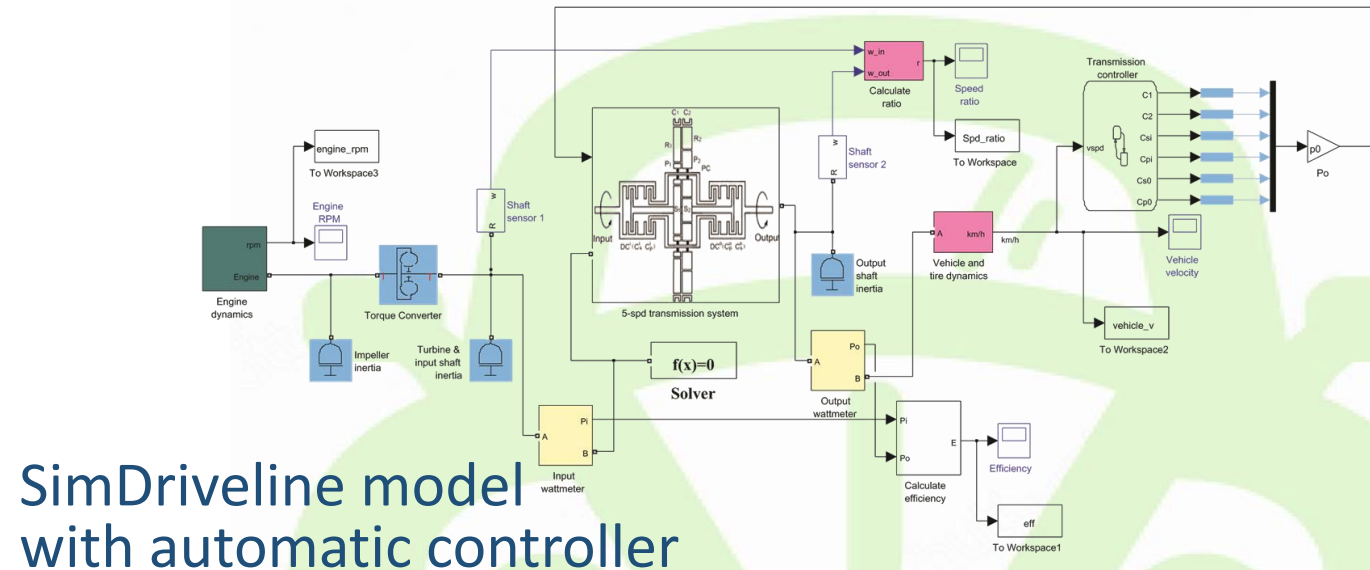


Transmission input/output velocities and gear ratios

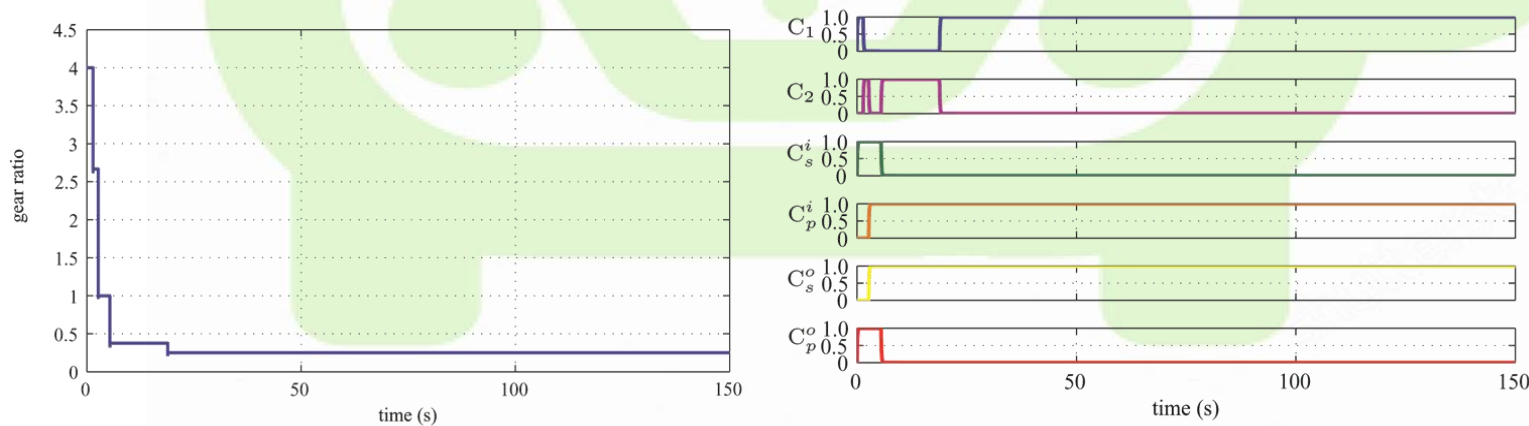
- Prescribed duration time for transmission modes
- Vehicle velocity has no effect on gear shifting
- Vibrations attenuated, but not realistic process

Preliminary Simulation : Transmission within Vehicle

Step 2: Controller with Real Time Control



Vehicle velocity



Transmission gear ratios and clutch schedule

- Real-time control for gear-shifting
- Feedback from current vehicle velocity
- More realistic vehicle operation

Work in Progress: Conclusions & Future Development

Phase I - Conclusions

- Novel concept of a modular automatic transmission with double dual-clutches for EV developed;
- Preliminary gear-shifting simulated and concept verified.

Phase II – Task definition

- Extended dynamic analysis;
- Gear-shifting simulation with dynamic input;
- Gear-shifting optimization criteria:
 - shifting time (minimum),
 - smoothness (transition amplitude – minimum);
- Transmission testing with optimized gear-shifting algorithm.

Questions?

