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PERFORMANCE EVALUATION OF TWO-SPEED ELECTRIC VEHICLES

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Two-speed EV schematic

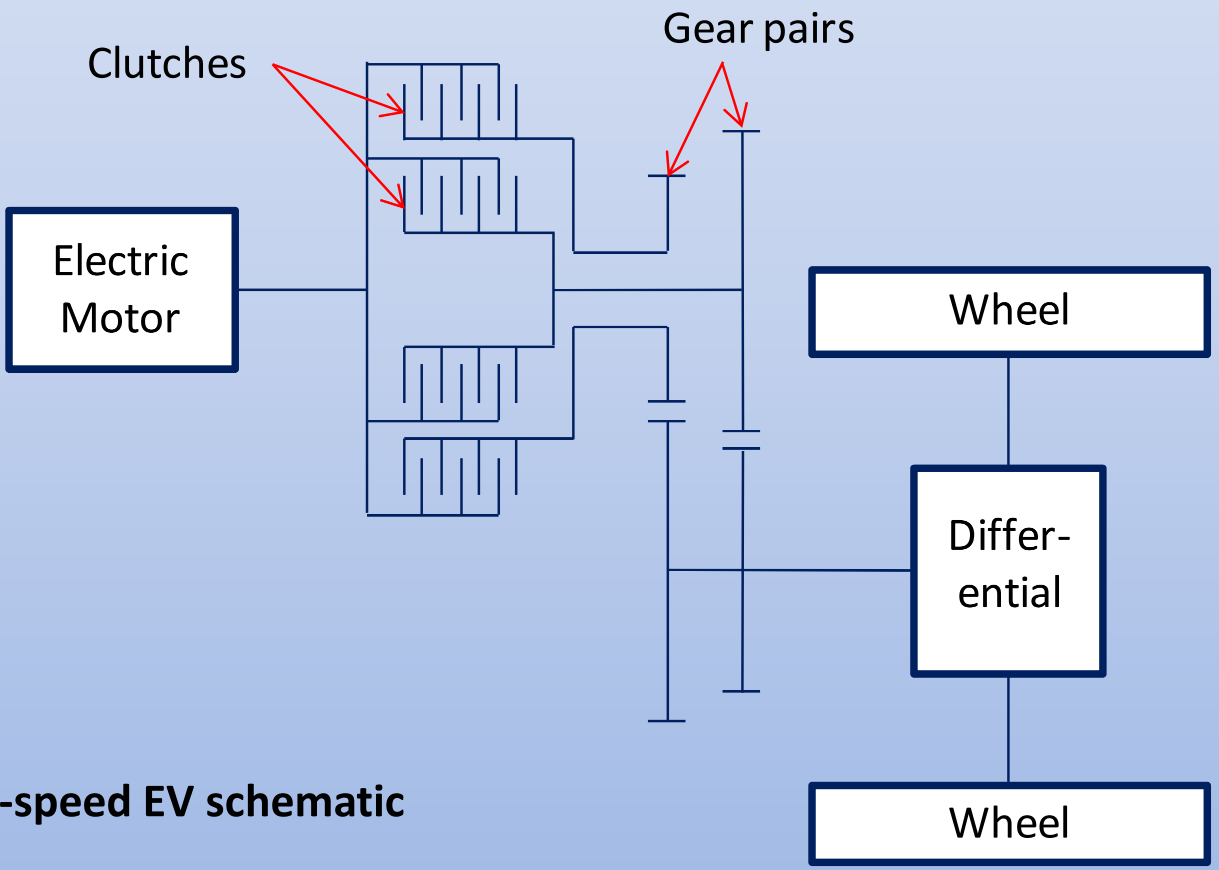

Fig. 1: Two-speed EV schematic

Distinction between single & two-speed EVs

- Theoretical traction curve defines the load delivered to the road
- Single-speed must trade peak load and top speed
- Two-speed can achieve both top speed and peak load demands

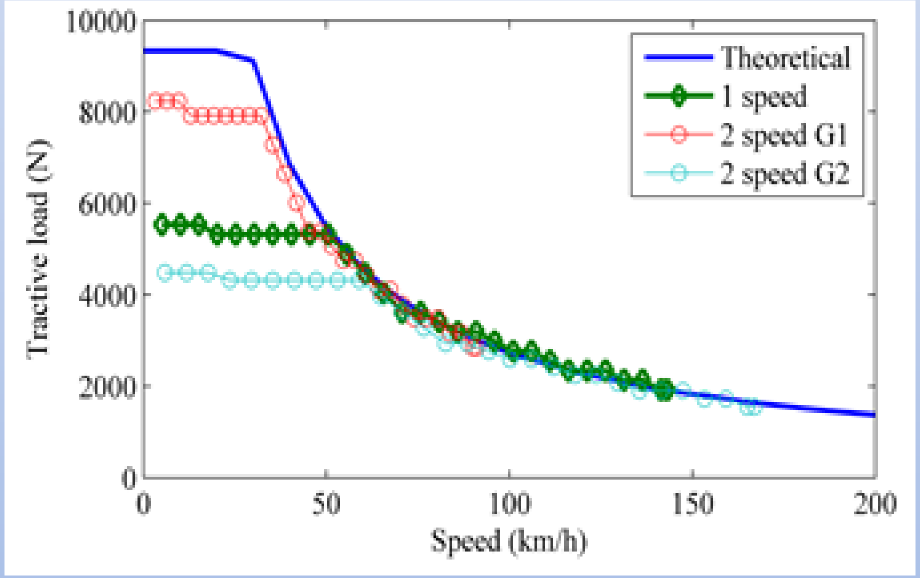

Fig. 2: Vehicle traction curve

Distinction between single & two-speed EVs

The assessment of tractive load characteristics leads to several design questions:

1. Can a multispeed EV out perform conventional EVs?
2. Is there a significant effect on vehicle range?
3. What is the influence on vehicle dynamic performance?
4. Ultimately, is a cost benefit achieved in the trade off?
    1. Reduced motor size reduces costs
    2. But we need to add a transmission + TCU + etc …

Simulation strategy

- Many methods available for evaluating vehicle range performance, i.e. L/100km, etc.
  - These are drive cycle based
- Limitations arise in designing the platform to beat one drive cycle only.
- Consider assessing the system operation across a range of driving cycles?
  - Broader evaluation strategy, but more time consuming.

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Electric vehicles power flow

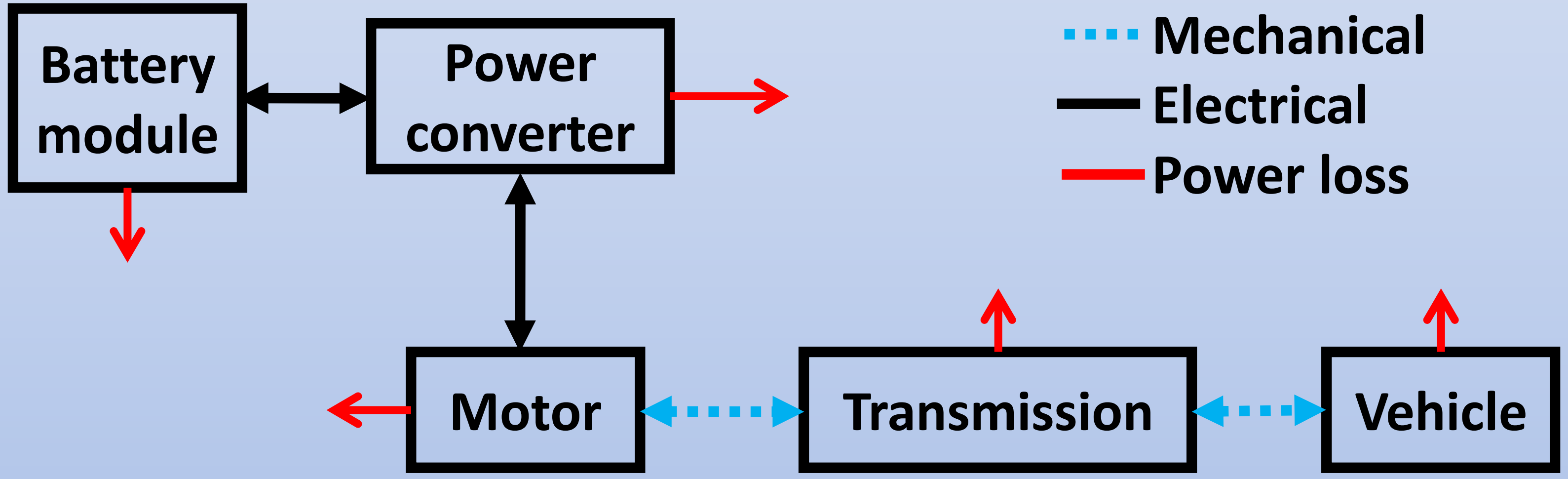

Fig. 3: Electric vehicle power flow

EV modelling

Power conversion and efficiencies in a powertrain:

- Electric machine

$$T_{EM} = \eta_{EM} \eta_{PC} \frac{P_B}{\omega_{EM}}$$

- Batteries

$$V_{OUT} = V_{OC} - R_{INT} \times I$$

- Vehicle

$$m_V r_t^2 \alpha = \eta_{PT} \gamma T_{EM} - T_V - T_B$$

$$T_v = \left(C_R m_V g \cos\phi + m_V g \sin\phi + 0.5 C_D \rho A_V \omega_V^2 r_r^2 \right)$$

Transmission control

- 2 speed DCT
  - No synchronisers – clutches continuously engaged
  - Shift schedule designed to maximise motor operating point in highest efficiency regions

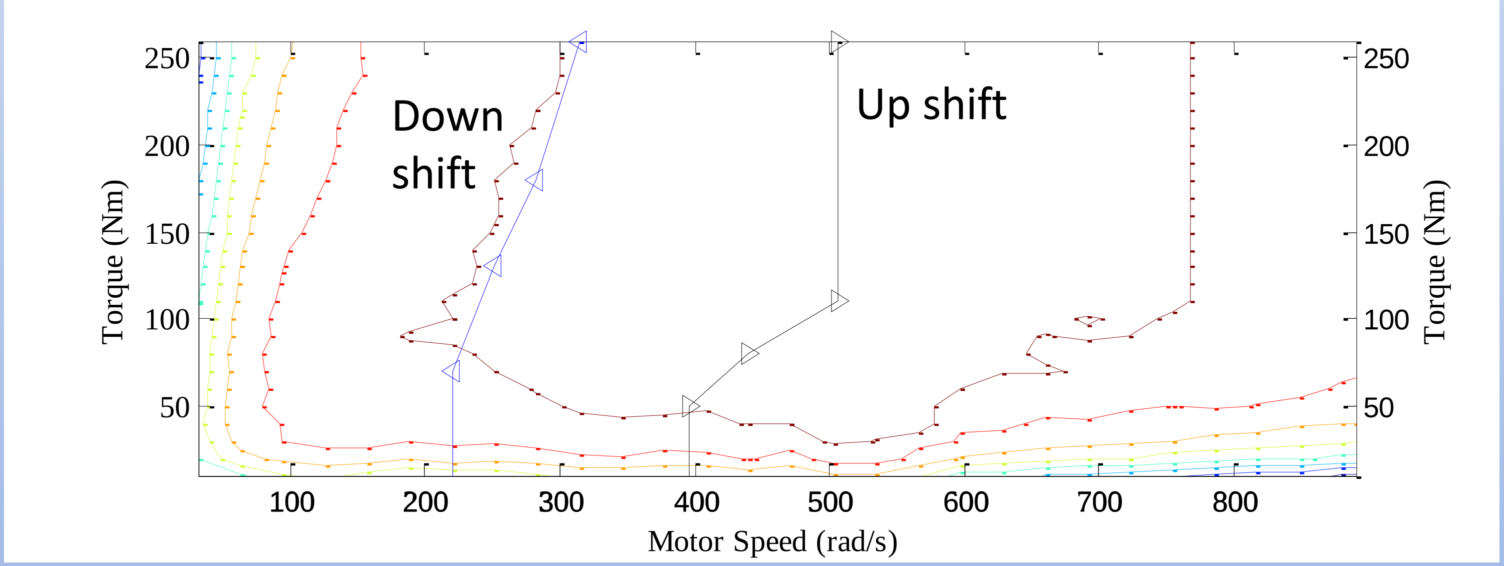

Fig. 4: shift map in comparison to motor efficiency

Evaluation of driving cycles for analysis

Drive Cycle	Duration (s)	Av. Speed (km/h)	Top Speed (km/h)	Single cycle Range (km)	Stopping Events
US06	600	77	129	12.9	6
HWFET	765	78	96	16.5	1
FTP75	1874	34	91	17.8	23
NEDC	1185	33	120	10.9	13
ECE	195	18	50	1	3
EUDC	400	62	120	7	1

Table 1: summary of driving cycles used in analysis

Influence of road grade on EV range

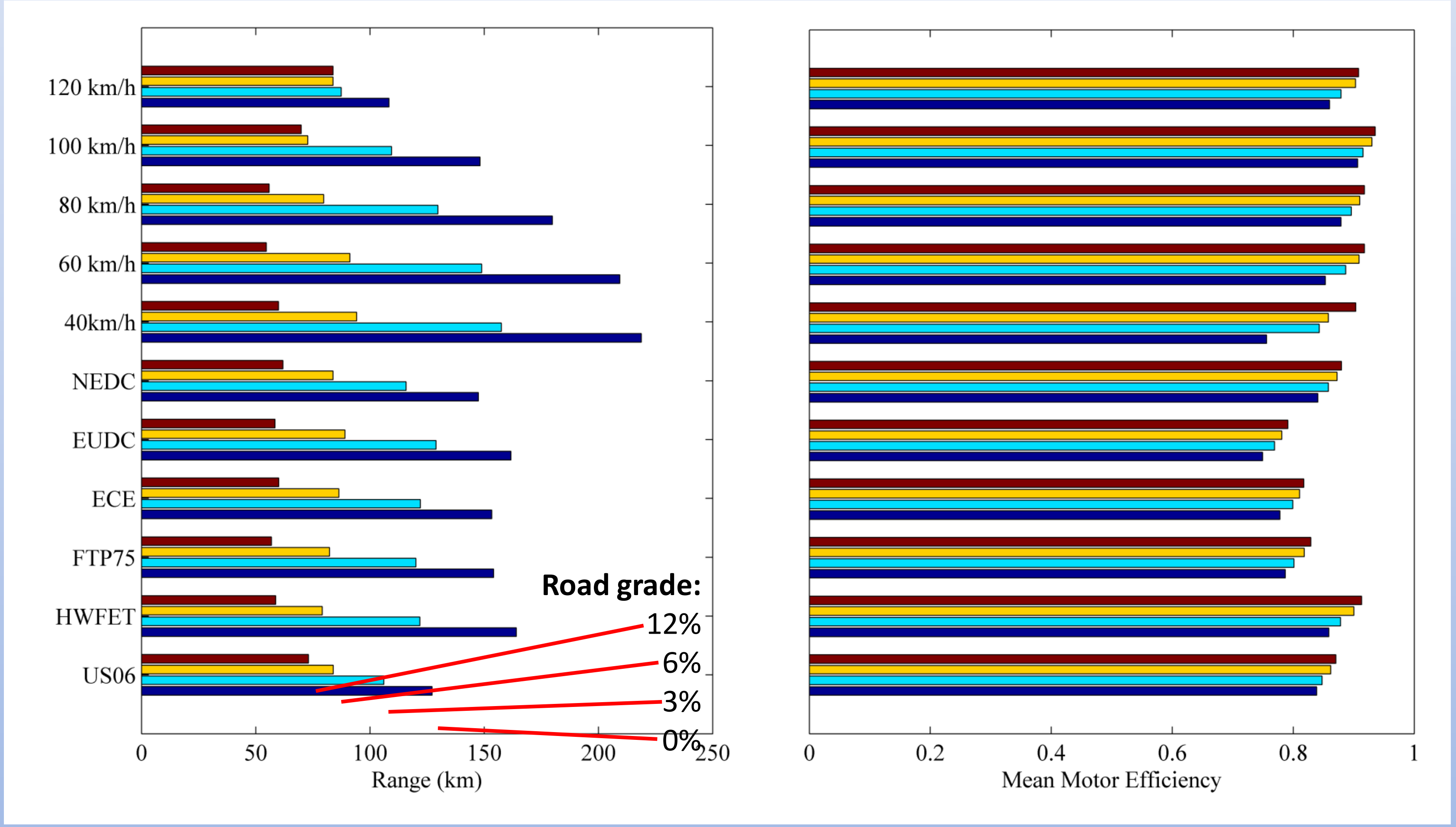

Fig. 5: vehicle range & average motor efficiency for different cycles with increasing grade

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Effect on motor operating efficiency

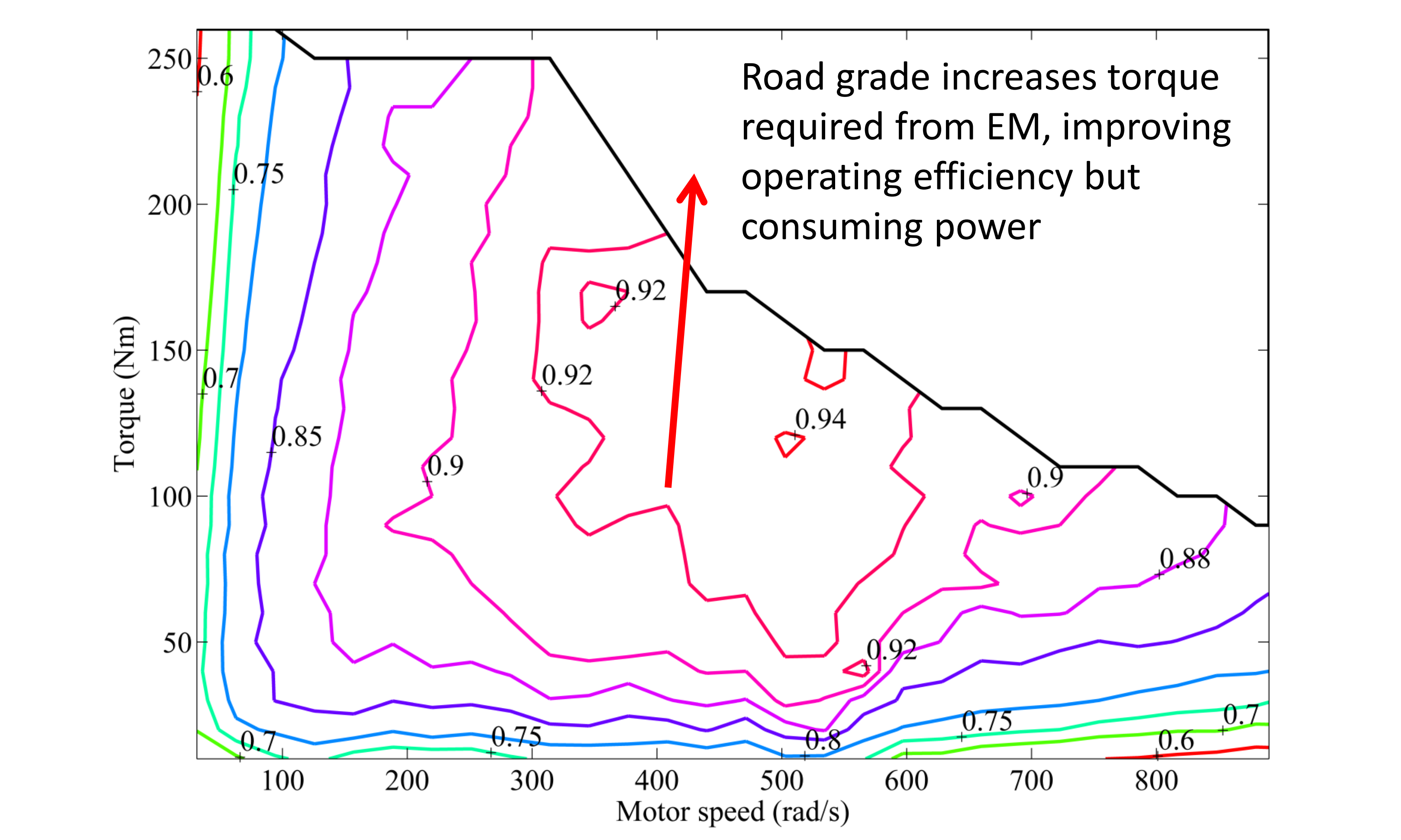

Fig. 6: Motor efficiency map considering impact of road grade

Influence of motor power on EV range

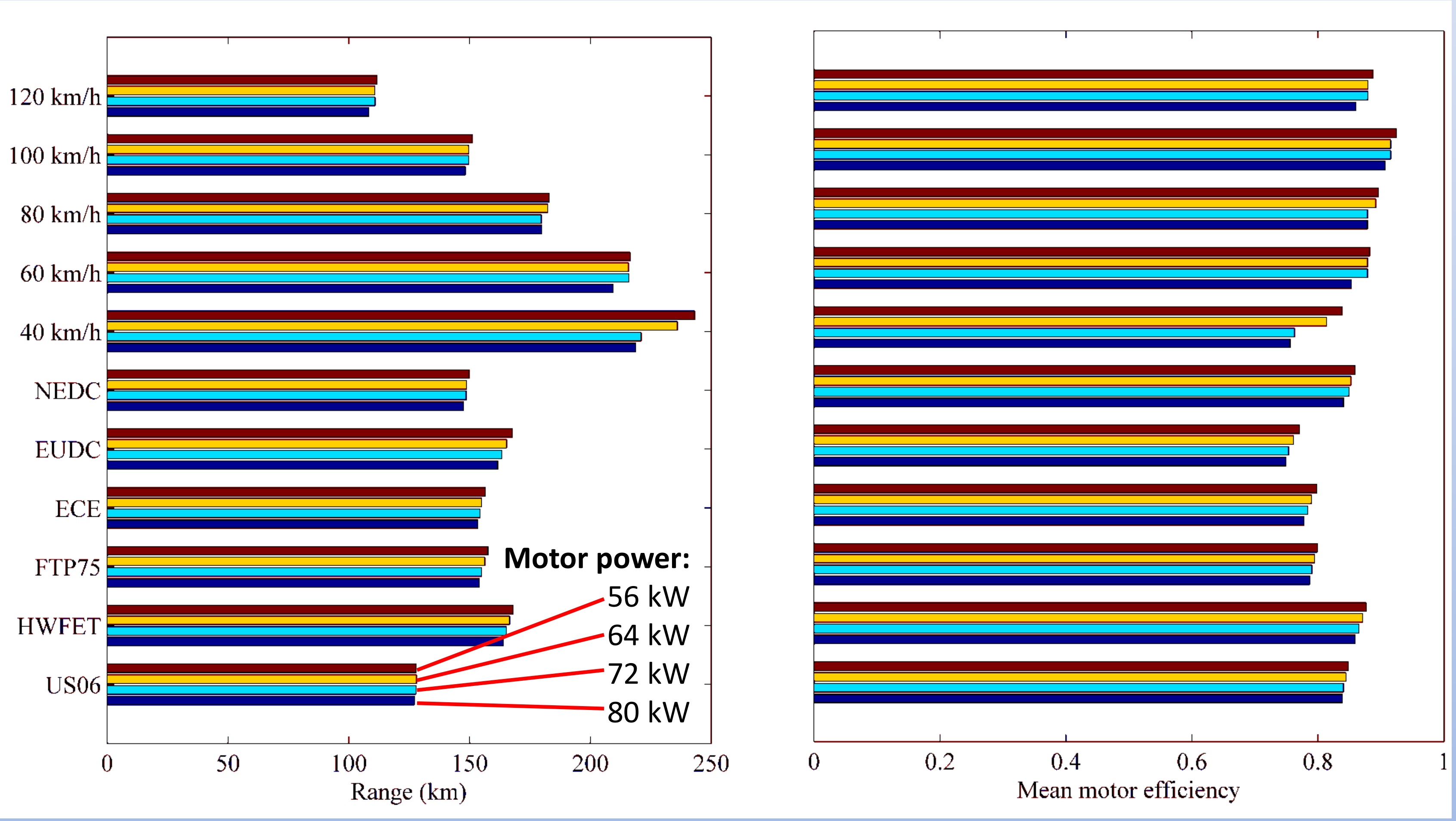

Fig. 7: vehicle range & average motor efficiency for different cycles with reducing power

Effect on motor operating efficiency

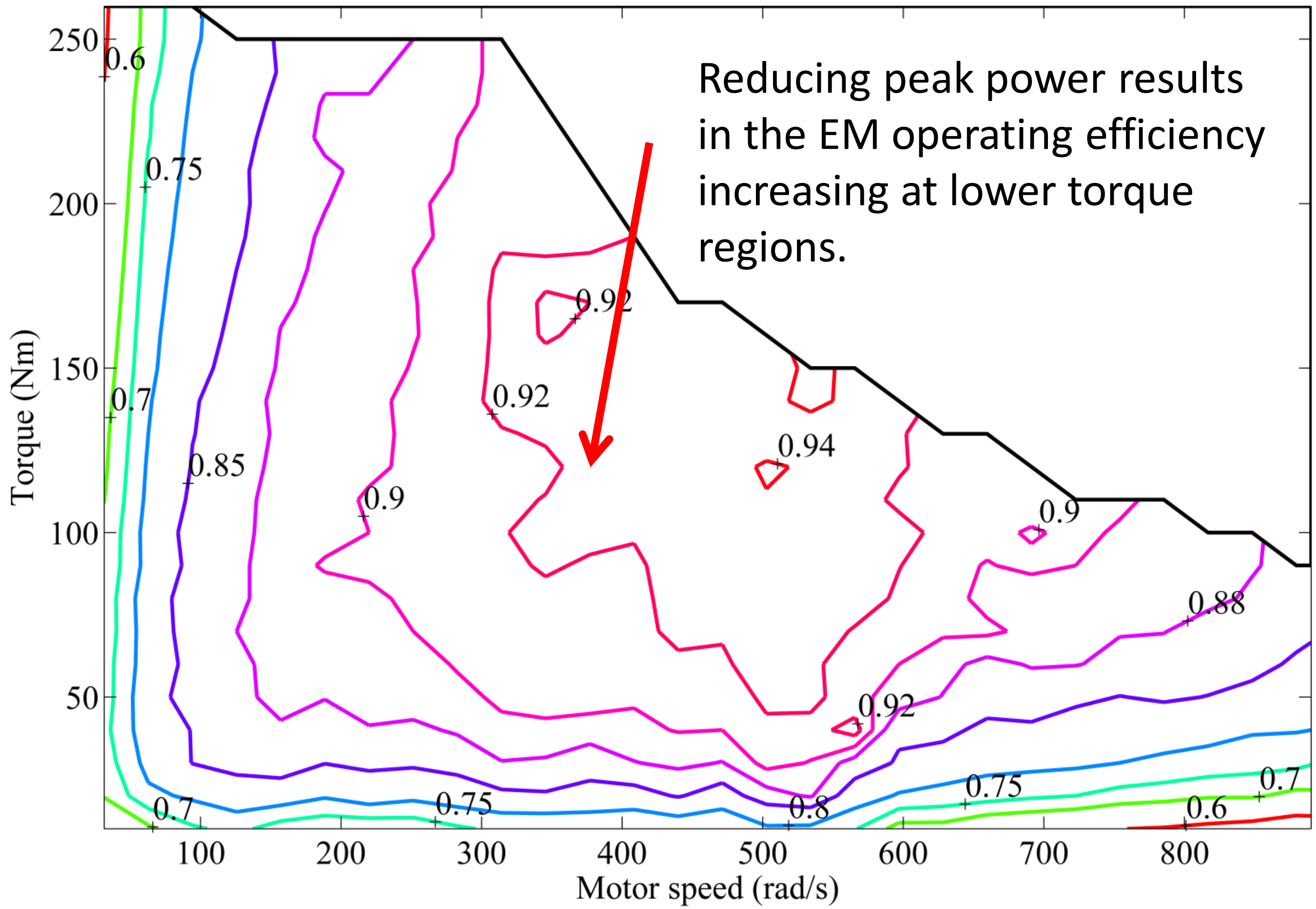

Fig. 8: Motor efficiency map considering the influence of reducing peak motor torque

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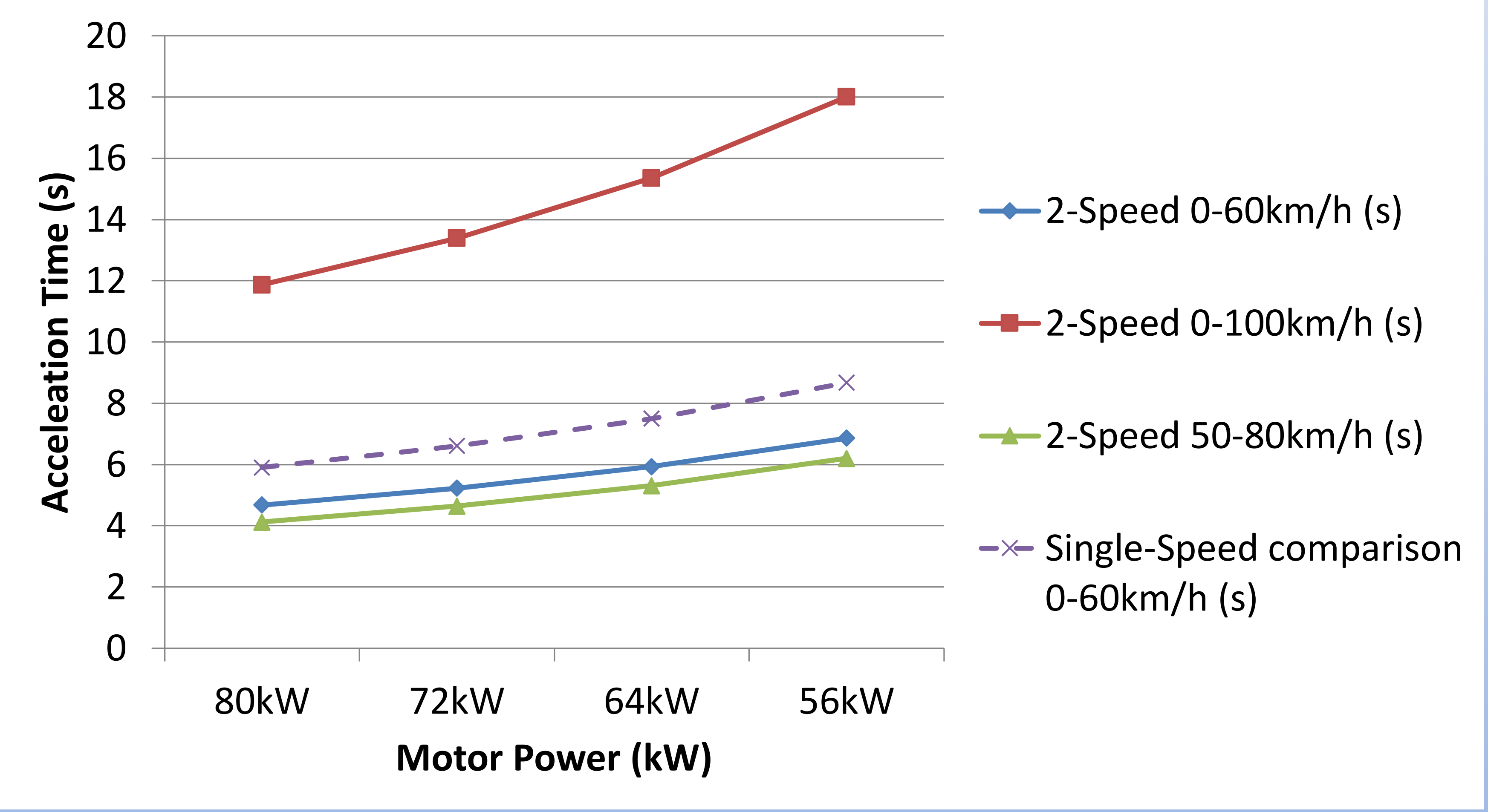
Influence on vehicle performance indices



Conclusions

- Improved driving economy, range, acceleration & climbing gradeability achievable with potentially smaller electric motors.
    - Vehicle performance is reasonable through significant reduction in motor size.
- Optimised two-speed DCTs combined with suitably sized electric motors offer vehicle designers more flexibility (acceleration, grade climbing, high speed performance).
    - Greater potential of energy recuperation.
- Further research & experimental validation required.

Thank you.

Questions & comments?