Engine Integration with 48V P2 Hybrid Vehicle for Fuel Economy

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HYBRID ELECTRIC VEHICLE ARCHITECTURES

ICE

Clutch

Gearbox

P0

P1

P2

P3

P4

P5

Rear axle

2018-10-08
GOAL & MOTIVATION

- A new simulation methodology in early phases of engine development (quick and accurate)
- Integration of engine model with vehicle model in GT-SUITE
- High variation possibilities in both engine and vehicle
ENGINE-VEHICLE SIMULATION

QUICK PROCESS AND ACCURATE ENOUGH
INTEGRATED VEHICLE-ENGINE

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Volvo XC60 T5, AWD</th>
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<tbody>
<tr>
<td>Engine</td>
<td>2 Litre 4-Cylinder Gasoline Direct Injection Cylinder Deactivation</td>
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<tr>
<td>Transmission</td>
<td>8 Speed Automatic Transmission</td>
</tr>
<tr>
<td>Motor / Generator</td>
<td>21 kW Electric Machine</td>
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<tr>
<td>Hybrid Technology</td>
<td>MHEV P2 Configuration</td>
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<tr>
<td>Battery</td>
<td>48 Volt System</td>
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<tr>
<td>Driver / Drive cycle</td>
<td>NEDC, WLTC, US06 &amp; RTS95</td>
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</tbody>
</table>

2018-10-08
ENGINE CALIBRATION RESULTS **WITHOUT CYLINDER DEACTIVATION**

**BSFC DIFFERENCE (SIMULATION VS. MEASUREMENT)**

Averaged absolute discrepancy = 1.6 %

### BSFC difference [%]

| Engine Speed [rpm] | 1000 | 1000 | 1000 | 1000 | 1500 | 1500 | 1500 | 1750 | 2000 | 2000 | 2000 | 2000 | 2500 | 2500 | 2500 | 3000 | 3000 | 3000 | 4000 | 4000 |
|--------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 1.5                | 4    | 8    | 12   | 1    | 2.62 | 5    | 10   | 8    | 2    | 5    | 12   | 16   | 5.5  | 8    | 12.6 | 7.5  | 10   | 16   | 5.5  | 12   |
ENGINE CALIBRATION RESULTS WITH CYLINDER DEACTIVATION

BSFC DIFFERENCE (SIMULATION VS. MEASUREMENT)

Averaged absolute discrepancy = 1.8 %

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</thead>
<tbody>
<tr>
<td>BMEP [bar]</td>
<td>1</td>
<td>1.5</td>
<td>1</td>
<td>1.6</td>
<td>2.26</td>
<td>5</td>
<td>2</td>
<td>3.2</td>
<td>5</td>
<td>6.4</td>
<td>1.6</td>
<td>3.2</td>
<td>5.5</td>
<td>6.4</td>
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</tbody>
</table>
VEHICLE RESULTS IN WLTC

REFERENCE VEHICLE: VOLVO XC60, 2L 4CYL ENGINE WITH CYLINDER DEACTIVATION & NO ELECTRIFICATION (NO STOP-START)
TIME DISTRIBUTION OF ENGINE OPERATION IN DIFFERENT DRIVING CYCLES

NEDC
7.7 l/100km

US06
8.8 l/100km

WLTC
7.5 l/100km

RTS95
10 l/100km
Cylinder Deactivation
BSFC Map

With cylinder deactivation (Ref. Vehicle)

Without cylinder deactivation

N.B. NVH limitation and switching loss are not considered.
21 KW ELECTRIC MACHINE IN WLTC

- Vehicle operating points on engine fuel consumption map in **WLTC**
21 KW ELECTRIC MACHINE IN WLTC

- Time distribution on engine map (%) in WLTC

\[
\begin{array}{c}
\text{Without 21 kW EM (Ref. vehicle)} \\
\text{7.5 l/100km} \\
\end{array}
\]

\[
\begin{array}{c}
\text{With 21 kW EM} \\
\text{6.9 l/100km} \\
\end{array}
\]
21 KW ELECTRIC MACHINE IN RTS95

- Time distribution on engine map (%) in RTS95
Constant Vehicle Speed Points on Engine Map

Available shifting strategy
(from Volvo, not optimized)

Aggressive shifting strategy
(Rough estimate, not optimized)
SENSITIVITY ANALYSIS

REF.: VOLVO XC60, AWD, 2L 4CYL ENGINE WITH CYLINDER DEACTIVATION & NO ELECTRIFICATION (NO STOP-START)

FUEL CONSUMPTION DIFFERENCE (%)
Ref.: 2l 4cyl engine (which has cylinder deactivation) on XC60 with no stop-start

- Removing cylinder deactivation reduces fuel economy in WLTC around 7%.

- Applying 21 kW P2 electric machine to the reference vehicle would lead to 8% fuel saving in WLTC.

- Removing cylinder deactivation at the presence of the P2 electric machine reduces fuel economy in WLTC to around 5%.

- The effect of cylinder deactivation is reduced at the presence of the P2 electric machine.

- The benefit of cylinder deactivation in RTS95 (4%) is less than that of WLTC; However, the benefit of the P2 electric machine in RTS95 is much more significant up to 17%.

- 5% weight reduction would lead to 3% fuel saving in WLTC.