Fuel consumption reduction potential of a Mild Hybrid system applied to a popular flex fuel vehicle
Terms Definition

Definitions for the proposed system:

“Battery state of charge” (SOC) means the quantity of electrical energy remaining in the battery relative to the maximum rated capacity of the battery expressed in percent.

“Charge sustaining” means that the battery of the hybrid electric vehicle ultimately does not fully discharge and impair vehicle operation as the vehicle continuously operates over a given driving cycle when no off vehicle charging is performed and the consumable fuel is regularly replenished.

“Regenerative braking” means the partial recovery of the energy normally dissipated into friction braking (deceleration period) is returned as electrical current to the battery.

“Hybrid electric vehicle “HEV” means that the vehicle can draw propulsion energy from both of the following on vehicle sources of stored energy: 1) a consumable fuel and 2) an energy storage device such as battery.

“Motor” refers to the electric motor

“Engine” refers to the combustion engine
Hybrid Vehicle characteristics:

Technical specifications Simulated in GT-Drive sw:

- Engine: 1.0 2V E100
- Vehicle weight: 1194 kg (additional weight 25 kg)
- CW: 0.34
- Frontal area: 2.01m²
- Tire: 175/65 R14GPS (green)
- Gear ratio: 4.17 / 2.3 / 1.43 / 0.98 / 0.78 / Diff 4.929
- Motor: 6.0 Nm (1000 to 18000 rpm) Max power of 11.31 kW
- Battery: 48 volts / 40 Ah
  - individual cylindrical cell: 50 mm width / 180 mm length
  - Width number of cells: 5
  - Length (number of cells): 10

Obs: The battery characteristics are input data for GT-Drive in order to estimate the SOC (state of charge)
Proposed Mild Hybrid system:

- Vehicle start on motor
- Start stop system
- Generator works only on vehicle deceleration
- Motor/Generator driven by a poly-V pulley
- Additional battery of 48V/40 Ah
- Motor works like a boost for the engine
- Considered Motor/Engine rpm ratio is 3:1
- $\text{SOC}_{\text{max}} = 0.85$ and $\text{SOC}_{\text{min}} = 0.45$

Obs: The Battery SOC is maintained inside this range by the ECU strategy, inverting from motor to generator.

BAS – Belt Alternator Starter. Motor / Generator driven by belt.
Mild Hybrid system Advantages Summary

Main advantages:

- Start stop system.
- Motor works in parallel to the engine, providing additional boost (better performance).
- Fuel consumption reduction under city and highway conditions.
- Possibility of improving cold start for Flex Fuel vehicles, due to faster cranking.
- Reduce oil contamination by liquid ethanol when the engine runs the cold phase (due engine load reduction/ under pressure improvement).
- Eliminate the actual engine starter (starter and booster motor and generator in one single unit).
- Regenerative system for the battery.
- Due to performance increase, there is a potential for further fuel consumption reduction using a longer transmission ratio.
GT-Drive model
Motor/generator is coupled directly to the engine crankshaft, replacing the standard alternator.

Drive ratio = 3.0 : 1
Strategy for cut-off and start-stop

Generator works when the engine is mainly in cut-off mode
The function of motor or generator is given by two tables for the actuator position according to the instantaneous battery SOC. Negative is generator and positive is motor.
The engine is all the time on except in cut-off mode or vehicle stopped. The electric motor works as
generator during deceleration at condition $\leq -0.038 \text{ m/s}^2$. 

Means the battery is in a “normal” SOC range

Battery is too weak

Battery is too strong
### Fuel consumption reduction

**1.0L 2V E100 Mild Hybrid**

<table>
<thead>
<tr>
<th></th>
<th>FTP-75</th>
<th>FTP-75(1)</th>
<th>FTP-75(2)</th>
<th>FTP-75(3)</th>
<th>HW(1)</th>
<th>HW(2)</th>
</tr>
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<tbody>
<tr>
<td>Fuel consumption</td>
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<td>Reduction %</td>
<td>12.73</td>
<td>9.44</td>
<td>8.34</td>
<td>6.04</td>
<td>15.44</td>
<td>13.00</td>
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<td>Combined(2)</td>
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<td></td>
<td>10.10%</td>
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</table>

- FTP-75 _ INIT SOC= 0.75
- FTP-75(1) _ INIT SOC= 0.60
- FTP-75(2) _ INIT SOC= 0.55
- FTP-75(3) _ INIT SOC= 0.45
- HW(1) _ INIT SOC= 0.75
- HW(2) _ INIT SOC= 0.55

**Obs:** In this comparison, the FTP-75 cycle for the hybrid version comprises measurement of 4 phases

**Fuel consumption reduction of 8.3% (FTP-75), 13.0% (HW) and 10.1% (combined) considering SOC=0.55**
Battery SOC estimation

\[ SOC = \frac{\text{Instantaneous Capacity}}{\text{Maximum Capacity}} \]

where:

\[ \text{Instantaneous Capacity} = Q_0 - \int i \, dt \]

and

\[ Q_0 = SOC_0 \times \text{Maximum Capacity} \]

Beside current and voltage, also temperature affects the SOC estimation. The instantaneous heat released (dissipated) in battery is given as follows:

\[ q = i \left( -C_i(T) \cdot T + \left( V_{oc} - V \right) \right) \]

- \( V_{oc} \): Open Circuit Voltage (defined by the Open Circuit voltage maps)
- \( V \): Voltage delivered (equal to the Battery Terminal voltage in cases where there is no resistance external to the battery).
- \( C \): Coulomb Efficiency which is only applied when the battery is charging.
- \( SOC \): State of Charge
- \( q \): Instantaneous heat release
- \( T \): Instantaneous temperature
- \( C_i(T) \): Temperature coefficient - \( C_i(T) = \left( \frac{dV_{oc}}{dT} \right) \)
- \( i \): Instantaneous current
Battery SOC (FTP-75)

The FTP-75 cycle starts at different SOC converging to 0.55
The HW cycle starts at different SOC converging to 0.55.
Battery Power Consumption (FTP-75)

Battery instantaneus power consumed at each point on FTP-75 cycle
Motor brake torque (FTP-75)

SOC = 0.55

Brake Torque
Motor Generator Map part BAS-1

Positive = Motor
Negative = Generator

Desenvolvimento do Produto
B-TPG: Powertrain Concepts

Volkswagen do Brasil
The battery power provided by the battery is higher than motor power due to electromechanical efficiency.
Motor brake torque (Highway)

SOC=0.55
FTP-75 1ª phase (505 s)

Gas pedal and brake pedal activation during FTP-75 cycle. The brake pedal actuation was calibrated thru a brake map as:

X = axle speed (rpm)
Y = Brake actuator position (%)
Z = Brake torque (Nm)
Desenvolvimento do Produto
B-TPG: Powertrain Concepts

The power provided by the motor was smaller than the requested due to battery capacity.