Fault-Tolerant Over-Actuated Hybrid Electric Vehicles

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Faults and their influence on the dynamic behaviour of electric vehicles

A fault classification method is developed to indicate the severity of a fault in a vehicle (above). Fault classification results for an inverter shutdown (below), shows a clear tendency for higher severity during high velocities, thus in the field- weakening range. Thereby, the vehicle stability index \( Q \) has the highest influence on the fault classification. The lane keeping index \( Q \), as well as the collision avoidance index \( Q \), have less significance. At motorway speeds, the controllability class reaches \( C \), for all wheel locations but the third.

Fault-tolerant control strategies for fault handling

The chosen control strategy is control allocation. It is able to generate useful solutions for faulty situations. Control allocation is a method that solves a mathematically under-determined problem. This occurs as soon as the number of controllable actuators is higher than the number of degrees of freedom, i.e. as it is in case of an over-actuated vehicle. The forces of the vehicle are distributed to the tyre forces as seen in the figure below.

Principle of control allocation
- Allocates the vehicle forces to the tyre forces.
- Under-determined mathematical problem.
- Optimisation and analytical approach available.

Results for a steady-state cornering manoeuvres

<table>
<thead>
<tr>
<th>x-distance in m</th>
<th>0</th>
<th>25</th>
<th>50</th>
<th>75</th>
<th>100</th>
<th>125</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fy (N)</td>
<td>100</td>
<td>90</td>
<td>80</td>
<td>70</td>
<td>60</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>Fx (N)</td>
<td>120</td>
<td>110</td>
<td>100</td>
<td>90</td>
<td>80</td>
<td>70</td>
<td>60</td>
</tr>
</tbody>
</table>

Example of a fault during driving

A yaw torque will be introduced in the vehicle without fault tolerant control. This results in a counter clockwise turning of the vehicle. Due to the reduction of side forces on the rear axle, the under-steering behaviour changes to a over-steering behaviour. The fault can lead to loss of vehicle stability.

A vehicle with integrated fault tolerant control is able to detect and isolate the fault. It allocates counteracting forces on the wheels to compensate for the occurring yaw torque. The vehicle directional stability and its speed is preserved, increasing safety for passengers and surrounding traffic.