Fault-Tolerant Over-Actuated Hybrid Electric Vehicles

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Preface

The hybridization of vehicle drivelines provides a mean for lowering the fuel consumption, thereby reducing the environmental impact of the vehicle. Several electric and hybrid-electric driveline configurations also offer other advantages including an improved maneuverability and an increased passenger safety. However, the introduction of drivelines containing power electronics and electric machines also raises important questions concerning reliability and behavior during electrical faults which, indirectly, affects passenger safety.

Scope of Project

The overall goal of this research work is to analyze the impact of failure modes (caused by electrical and other faults) and the degree of in-built fault-tolerance for different vehicle control strategies in electric and hybrid-electric drivelines. Particular focus is on hybrid electric vehicle concepts where propulsion power is obtained from light in-wheel motors at each wheel. The solutions will be depending on which forces that do occur and which sensors and actuators that are available. The vehicle control strategy will also be depending on actual type of failure mode. Finally, verifying measurements of the level of fault-tolerance for various vehicle control algorithms on a scaled-down vehicle prototype is planned.

Project Timeline

2010-Q2 - Start of Project within the Swedish Hybrid Vehicle Center.

2010-Q3 - Literature survey in vehicle control, fault management and electrical machines.

2010-Q4
- Modeling of an over-actuated vehicle with light in-wheel motors.
- Classification of electrical and other faults into failure classes.
- Determination of different kinds of over-actuation.

2011-…
- Implementation of transient models of the in-wheel motors fulfilling specs for a small passenger vehicle.
- Analyze the impact of different motor control strategies during electrical faults in vehicles with different levels of over-actuation.
- Classification of different kinds of failure modes in the vehicle.
- Derive different type of transient models of the in-wheel motor valid during different classes of electrical faults.
- Study possible effects of faults on the dynamical behavior of the vehicle with different levels of over-actuations.
- Development of solutions for fault detection and compensation.
- Validation and verification of the developed strategies deploying a scaled-down vehicle.

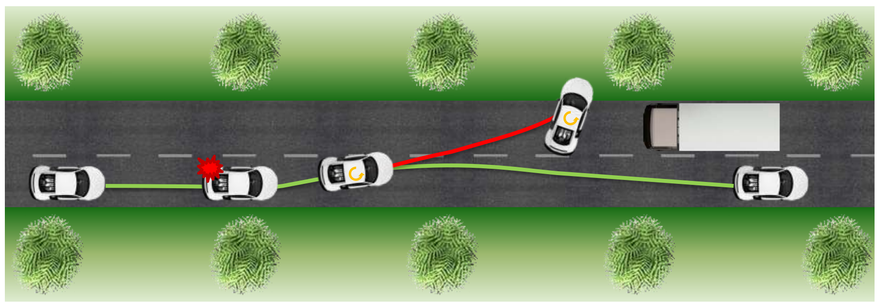
Example of a Fault Situation

Imagine a passenger car equipped with new x-by-wire technologies, like an over-actuated corner module vehicle, drives on a country road. A dangerous situation could occur, if for instance the rear left in-wheel motor fails either by locking itself or by producing a negative torque.

Vehicle without fault tolerance (red)

Applying no automatic counteraction to an occurring fault, a yaw moment will be introduced in the vehicle. This results in a counterclockwise turning in of the vehicle. Due to the reduction of side forces on the rear axle, the vehicle's under-steering behavior changes to a over-steering behavior within a split second. A driver will not be able to react with the correct counteractions, thus the fault leads to the loss of the vehicle's stability.

→ The vehicle will leave the expected path and increases the risk of a severe accident.



without fault tolerance

with fault tolerance

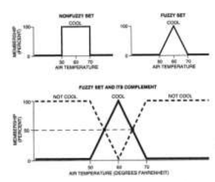
Vehicle with integrated fault tolerance (green)

An automated counteraction will be conducted as soon as the occurring fault is detected and allocated. This process happens within some milliseconds. Thus the fault will be handled immediately after its appearance. A fast rerouting process within the physical boundaries will be initiated to guide the vehicle onto its previous path. The driver will not necessarily be involved in the rerouting process.

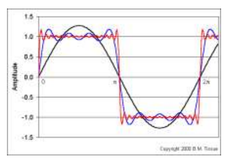
→With less risk of accidents the safety for the passengers and other traffic participants decreases.

→ New fault handling strategies are highly recommended for increasing the overall vehicle safety.

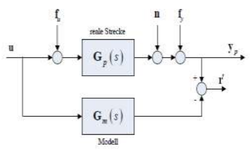
Fault Detection and Fault Diagnosis Methods



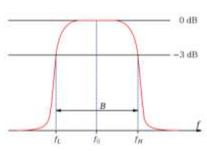
Fuzzy Logic



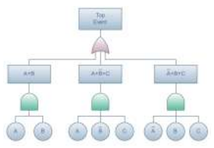
Fourier Analysis



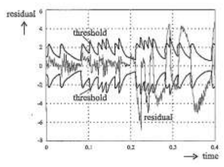
Parity Equations



Bandpass Filter



Fault Tree Analysis

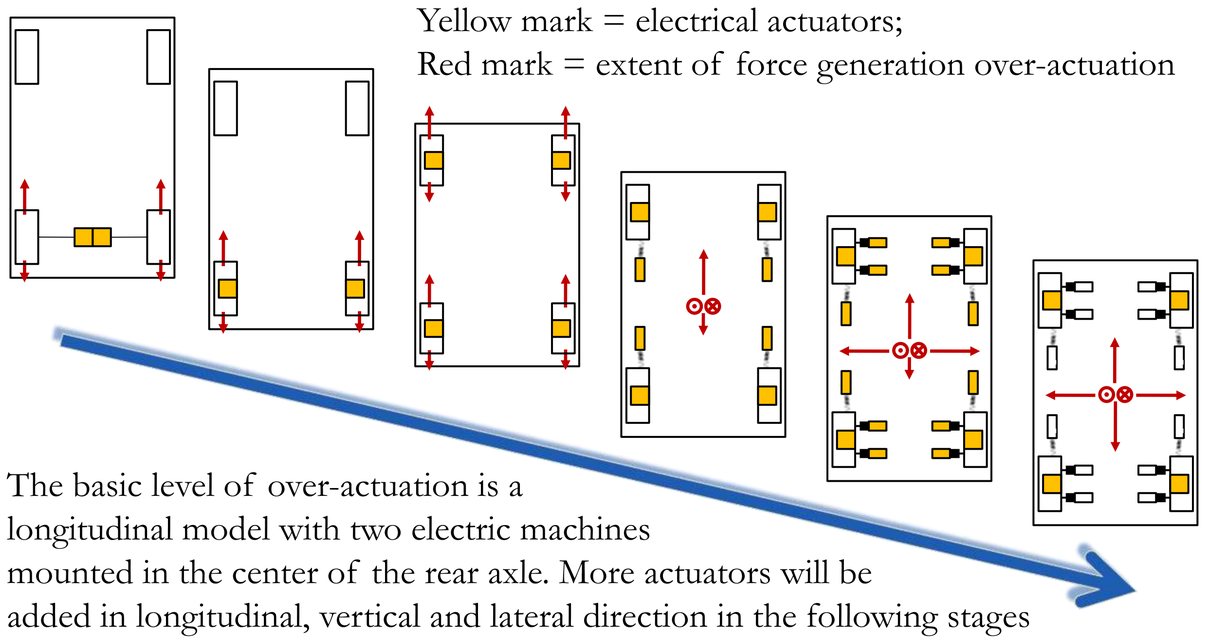


Thresholds

Different Levels of Over-Actuation

The fault tolerant strategies will depend highly on the type of over-actuation considered. Therefore six different levels of over-actuation are analyzed.

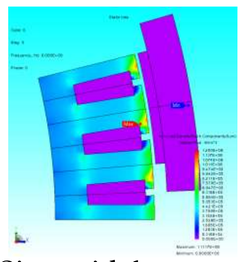
Yellow mark = electrical actuators;
Red mark = extent of force generation over-actuation



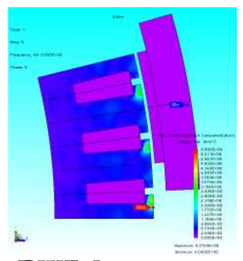
The basic level of over-actuation is a longitudinal model with two electric machines mounted in the center of the rear axle. More actuators will be added in longitudinal, vertical and lateral direction in the following stages until a fully over-actuated corner module. The main advantages of this approach are the focusing on single subsystems, the heritage of developed solutions and proximity to series application in the vehicle industry.

Electric In-Wheel Motor

In cooperation with KTH Electrical Machines and Power Electronics a detailed transient model for the in-wheel motors is developed. A finite element analysis is carried out in order to find the best configuration. Transient models are implemented into the different levels of over-actuation. Here the loss distribution of the stator is shown:



Sinusoidal current



PWM current

Acknowledgements

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