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Smart Torque Vectoring Functionality for AWD Electric Vehicles

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Summary

While restrictive CO_2 legislation targets claim for sustainable mobility, electrified powertrain concepts emerge as a mainstream solution. In this context, full electric vehicles represent a solution with the capability of local pollutant emission free driving and zero tank-to-wheel CO_2 emissions. One of the major limitations of battery electric vehicles is the limited range of the vehicle especially under real life conditions. Therefore, technical solutions that reduce the electric energy consumption are of high interest especially for electrified powertrain concepts.

Within this paper, FEV presents a battery electric vehicle motored by two electric motors mounted respectively on the front and rear axles. For this electric vehicle topology, FEV developed a dedicated axle torque split algorithm to optimize the powertrain efficiency and improve the vehicle electric range with focus on real life driving conditions. The functionality takes into account the system operational constraints (e.g. electric motor continuous and peak power limits and TCS-based vehicle traction limits), driving comfort as well as manoeuvrability limits to optimize the overall system behaviour.

The overall system is tested within a dedicated Model-In-the-Loop 3D plant model capable of longitudinal and lateral vehicle dynamics including MATLAB/Simulink and IPG CarMaker®. The results show a reduction of total energy demand by 1.6 % to 2.9 % in WLTC comparing to different baselines. In terms of driving dynamic improvement, a noticeable increase of the launch acceleration on a µ-split ground can be detected in a certain test case.

Keywords: Torque Vectoring, Energy Consumption, Traction Control, AWD.

1 Introduction

Today's automotive development is characterized by the increasing challenge of fulfilling emission legislation while offering the customer an attractive vehicle with enjoyable drivability. Battery electric vehicles offer the ability to drive without local emissions combined with excellent acceleration performance due to the torque characteristics of the electric motors (EM). In order to fulfill higher power demand of certain vehicle classes, such as SUVs, it is motivated to use more than one electric motor in the powertrain. In addition to higher power output, the usage of two separately propelled axles in an all-wheel drive (AWD) powertrain furthermore allows the additional functionality of a virtual differential, economically distributing the torque between the two axles or actively locking an axle with unintended wheel slip. This on one hand enables more sophisticated vehicle functions than conventional mechanical differentials, and on the other hand reduces overall system complexity compared to advanced torque controlling differential.

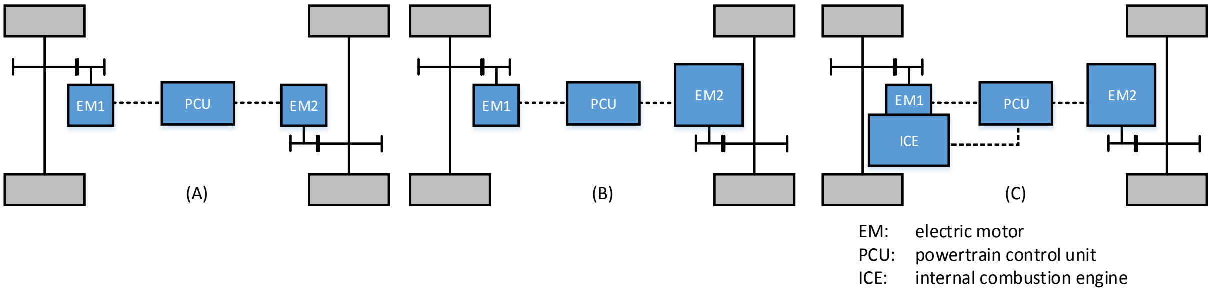

Figure 1: Simplified System Topology

This paper describes a smart front/ rear torque vectoring function which is developed by FEV for AWD electric vehicles with axle-split powertrain topology. This topology covers different variations, which have two electric motors coupled to front and rear axle respectively.

1. Symmetrical topology where motors and gear ratios are identical on both axles, as shown in Figure 1 (A).
2. Asymmetrical topology where the motors and/or gear ratios are different on both axles, as shown in Figure 1 (B).
3. Electric powertrain part of an axle-split hybrid powertrain, where one EM is coupled with ICE and the other on a different axle, as shown in Figure 1 (C).

The smart torque vectoring function integrates the economic torque split function, which maximizes the driving range by minimizing the overall energy loss; and the slip control torque split function, which shifts the torque on the slipping axle to the non-slipping axle in order to maintain desired acceleration on low µ surfaces.

2 Motivation

Major benefit from the torque vectoring function is the possibility to distribute the torque to the front and rear axles to achieve optimal system efficiency, and in the same time to utilize the maximum available battery power. On the contrary to a fixed torque split ratio, which is normally adopted by conventional differentials for AWD vehicles, an AWD electric vehicle with axle-split powertrain topology has the flexibility to dynamically allocate the total wheel torque request, and therefore the following advantages can be expected:

1. Optimum system efficiency can be realized, and therefore driving range can be extended.
2. In case the battery power output cannot fulfill the wheel torque request due to low state of charge or other ambient conditions, optimum torque distribution can maximize the mechanical output to improve the drivability.
3. For asymmetrical powertrain topologies in specific cases, as shown in Figure 2, a fixed torque-split ratio, for example 0.5, may fail to fulfill the wheel torque request even though the system is able to. In this example, EM2 is in field weakening area, which cannot cover 50 % of the wheel torque request. However, wheel torque request can still be covered by increasing the torque request to EM1 and decreasing the torque request to EM2.

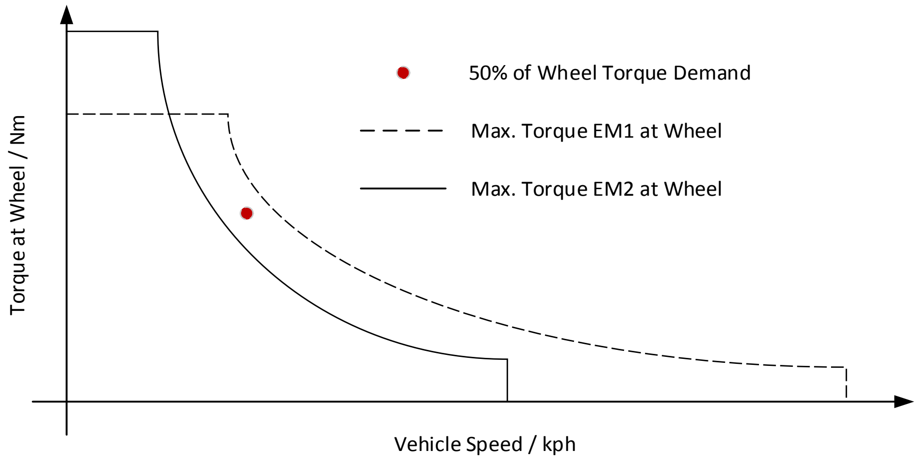

Figure 2: Potential Failure of Fulfilling Wheel Toque Request with Fixed Torque Split Ratio

In drive dynamic perspective, benefits can be expected from front/rear torque vectoring also. By cornering, the traction force can be intelligently allocated to the front and rear axle to achieve desired steering behaviour. Another example is that on a µ split surface, the slipping axle may be braked by traction control system. If the torque request on the slipping axle can be relocated to the non-slipping axle, both efficiency and drivability can be improved.

3 Methods

3.1 System Efficiency Optimization

Electric motors in an AWD electric powertrain use the same energy source, namely the high voltage battery. This guarantees a global optimized torque distribution over time, by seeking local optimum torque distribution in regard of efficiency during electric drive in real time.

As multiple dynamic effects such as torque and power limitations for different components have to be taken into account, the optimum torque split ratio is selected to be calculated numerically online, instead of using multiple off-line calculated look-up tables, which requires significant memory usage.

At first, the torque split ratio Φ_T and power split ratio Φ_P can be defined according to (1) and (2) respectively.

$$\Phi_T = \frac{T_{RA}}{T_{WhlReq}} \tag{1}$$

where:

T_{RA} *is torque request to rear axle at wheel*

T_{RA} *is total wheel torque request*

$$\Phi_P = \frac{P_{RA}}{P_{WhlReq}} \tag{2}$$

where:

P_{RA} *is power request to rear axle*

P_{WhlReq} *is total wheel power request*

During operation, the maximum and minimum value of Φ_T and Φ_P are firstly calculated according to the real time component limits. After that, it should be judged with a look up table, whether the battery power is sufficient to cover total wheel torque demand. In the end, the optimum Φ_T is calculated with the pseudocode shown below:

```
if  battery power sufficient:
    Iterate torque split ratio $\Phi_T$ of demanded torque within the calculated range, find the one with the minimum power loss
else
    Iterate power split ratio $\Phi_P$ of battery power within the calculated range, find the one with the minimum power loss. Convert the power demand into torque demand, and then calculate the corresponding torque split ratio
end
```

3.2 Driving Dynamics Improvement

One of the driving dynamic related function is that it reacts on the feedback of the TCS (traction control system), indicating individual wheel slip to the algorithm. As soon as a slip is detected, a highly dynamic controller starts shifting torque from the slipping axle to the other in dependency of the current torque and the drive mode. This increases not only vehicle maneuverability but also the performance of the vehicle during accelerations significantly [1].

4 Results

The improvement of the vehicle behavior in simulation environment which is developed at FEV. Functions are validated in different test cases with different powertrain topology, in order to show the best potential of the function. Energy economy improvement is examined with an asymmetrical AWD electric powertrain along WLTC, considering no torque intervention. In case of torque intervention scenario, the performance of an electric vehicle with symmetrical AWD powertrain is examined in a dedicated test case where vehicle is accelerated on a µ-split surface.

4.1 Simulation Environment

The developed smart functionalities are tested in a dedicated Model-In-the-Loop 3D plant model capable of longitudinal and lateral vehicle dynamics within a toolchain that includes MATLAB Simulink® and virtual driving test software IPG CarMaker®. As shown in Figure 3, the plant model combines the electrified powertrain from FEV´s MATLAB/Simulink library; the driver, tires and road models are implemented in IPG CarMaker®. This toolchain combines detailed powertrain dynamics, accurate vehicle lateral and longitudinal dynamics and the actual control strategies implementable in the real vehicle. The powertrain and vehicle data are based on different real vehicle specifications from FEV database. Energy economy, performance and driveability behaviour are in a range of accuracy of ± 5 % in terms of integral values.

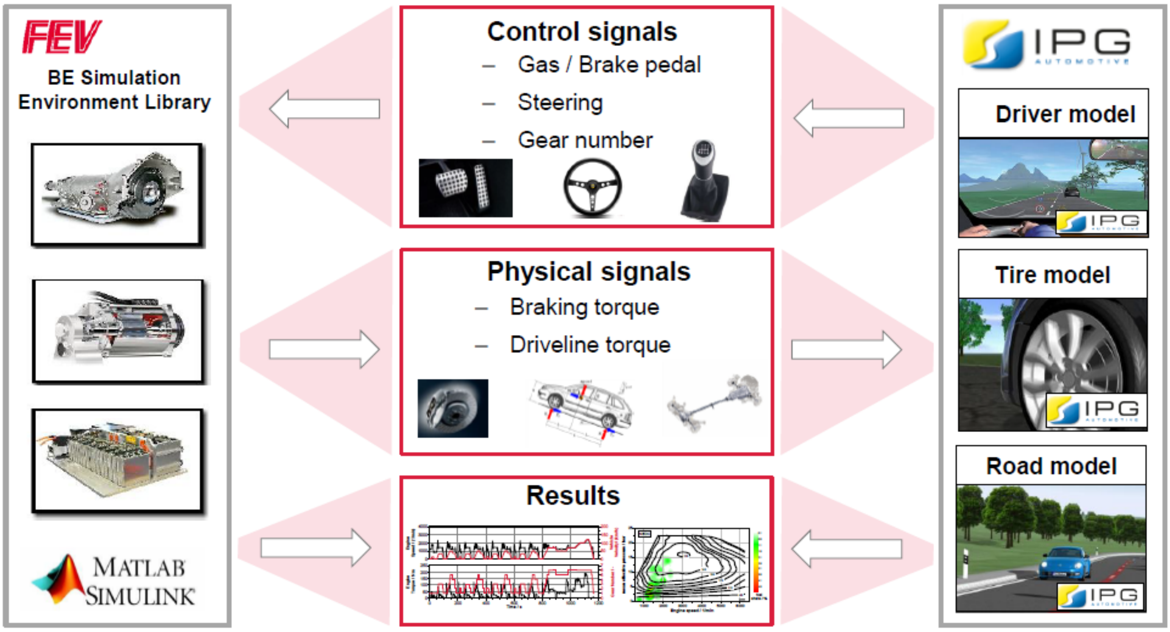

Figure 3: Co-Simulation Environment with Simulink and IPG Carmaker® at FEV

4.2 Test Cases for System Efficiency Optimization

Torque split function under conditions without Traction Control System (TCS) intervention is tested with a B-Class vehicle with an axle-split electric powertrain. The front electric motor is coupled to the wheel with 2 gears, while the rear electric motor with a fixed gear. The optimum torque split is compared with a fixed torque split ratio of 0.5 and 1, where the latter case is taken as baseline, and means that the rear electric motor tends to cover the torque demand as much as possible.

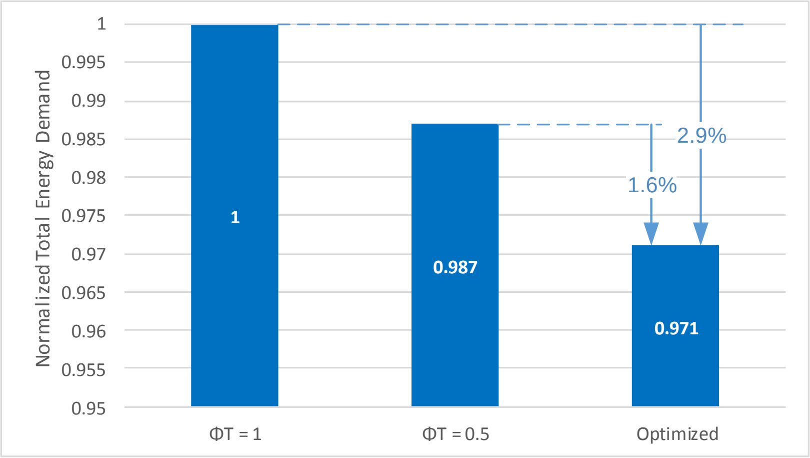

Figure 4: Comparison of Total Energy Demand with Different Torque Split Ratios in WLTC

As shown in Figure 4 the optimum torque split reduces driving energy by 2.9 % comparing to a constant torque split ratio of 1, and 1.6 % comparing to a constant torque split ratio at 0.5.

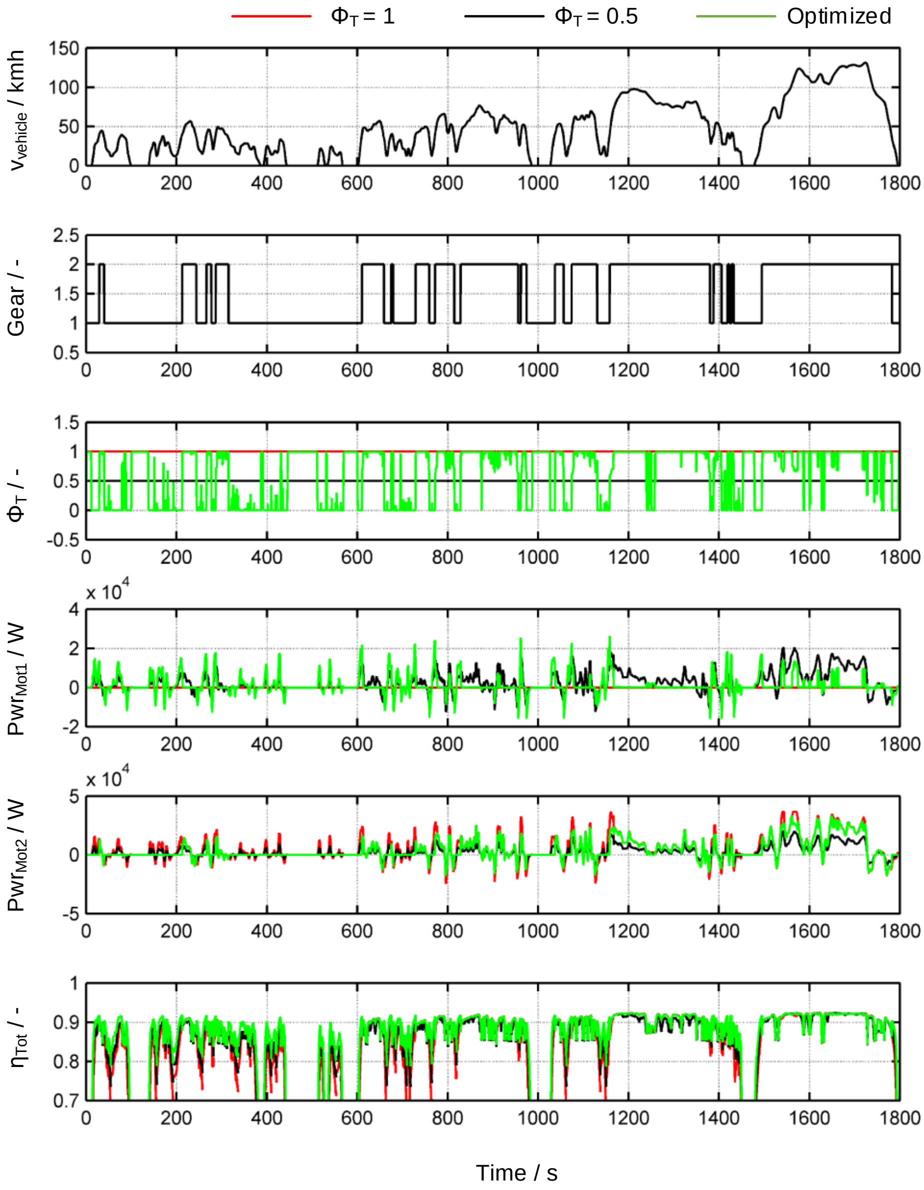

Figure 5: Simulation Result Comparison with Different Torque Split Ratios

In Figure 5, detailed simulation results from different torque split ratio is presented. Comparing to a constant ratio of torque distribution, an optimized torque split tends to operate the powertrain with only one electric motor, even considering the drag loss from the non-operative motor. The selection between the front and rear motor is depending on the gear position of the front motor. This is because the optimum operation range of electric motor is normally at higher load. It should be noted that by decoupling the non-operative motor from the powertrain, energy consumption can be further reduced, since the drag power at zero torque operation can be decoupled from the powertrain.

4.3 Test Case for TCS Intervention

In terms of driving dynamic, the system allows a smart control of the single axle torque. In particular, during driving phases at high power demand, the capabilities on the single axles are reduced and the best torque split is allowed between the two axles. The functionality guarantees that the individual torque limit (including the derating) of the electric motors and battery is never exceeded. The torque split functionality is checked in coordination with the TCS intervention with vehicle starting from standstill condition with rear tires on low friction road surface (μ = 0.2) with moderate acceleration. One can see in Figure 6 as an extraction from IPG Carmaker® simulation, that the vehicle with activated smart torque vectoring has better acceleration by shifting the torque demand to the front axle and therefore avoiding a slipping rear axle on the low friction surface.

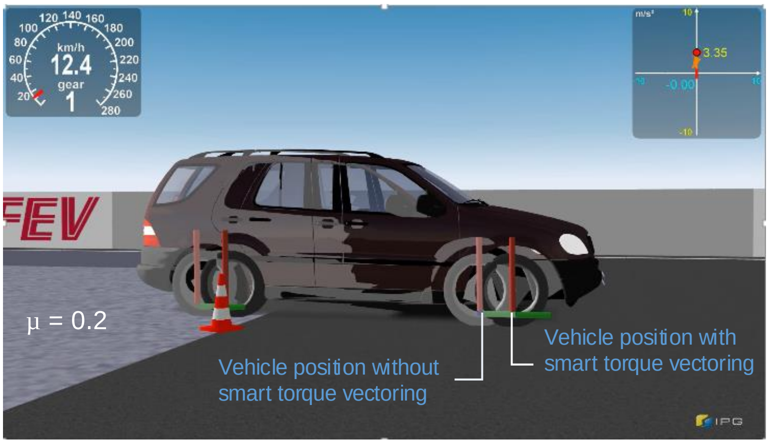

Figure 6: Acceleration Test – Dynamic axle torque shift reduces wheel slip to improve vehicle acceleration with μ-split

5 Discussion and Conclusion

The smart torque vectoring function described in this article allows a significant reduction of the energy consumption by re-locating the torque request to the two electric motors to achieve the optimum system efficiency. Furthermore the additional driving dynamic benefits in terms acceleration on μ-split surface is realized. The functions were evaluated in a simulation model, which co-simulates with the virtual driving test software IPG CarMaker®.

In the next steps, FEV will investigate the possibility for further enhancements of the functionality by considering predictive information from navigation data and global navigation satellite system (GNSS). Thereby the algorithm can be qualified to anticipate for example corners and slippery roads before the vehicle reaches them. The additional opportunity not only to react to slipping wheels but to avoid them with the prediction will be the next step to even further increased vehicle manoeuvrability and the safety of the driver.

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