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Innovative Testing Process for Electric Powertrains

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Summary

Actual and future electric vehicles contain complex powertrain hard- and software which has to be tested carefully. Efficient test processes and procedures are needed to ensure highest product safety, reliability and performance of the complete vehicle. The paper presents a new approach for the testing process of electrical powertrains with only real components available on test beds distributed over different test sites. The result of this work extends the established test method “from-road-to-lab” with interconnected test beds. The approach makes component testing inside a fully functional virtual car in real-time possible. The paper will describe in detail the prototypical implementation of this testing process for a battery electrical vehicle with wheel hub motors and torque vectoring.

Keywords: *Electric powertrain - Component testing – Real-time simulation - Connected test beds*

1 Introduction

One of the challenges in testing of electric vehicles is the huge number, variation and interaction of components and functions inside the fully integrated vehicle. A large effort on testing is needed to guarantee a save and reliable system. Especially suppliers need test procedures for their components on the fully integrated car, but normally they have no or limited access to such a real prototype vehicle. The final validation for all integrated components in the vehicle is done by the OEM on private test tracks and public roads. Figure 1 depicts a typical schedule for iterative testing in the vehicle prototype.

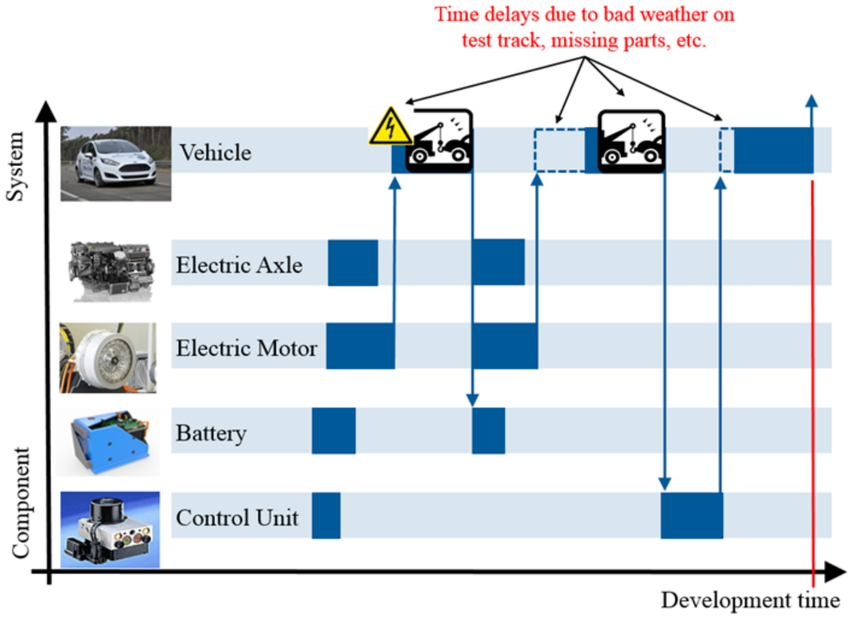

Figure 1: Challenge for the testing process of electric powertrains

On this background a new approach for the testing process of electric powertrains is presented. The process allows tests on a fully integrated virtual car with only powertrain components available on test beds. It combines Hardware-in-the-Loop testing and connected component test beds in an early development phase as shown in Figure 2. The virtual car is built-up by real components on connected test beds. The chassis and all other relevant systems and components are simulated in real-time on a computer. The tests beds are connected with each other and with the simulation model via real-time capable and secure Ethernet. This combines the well-established "Road-to-Lab" approach [1] with the possibility to perform integration tests on distributed component test beds at an early development stage. For example the electric motors and the battery are tested at the same time on their respective test beds and components like the steering system are simulated within the real-time computer.

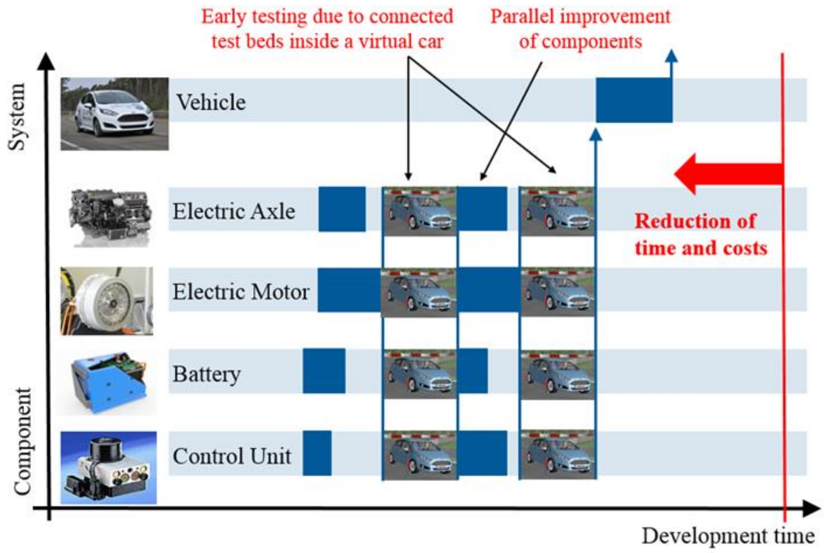

Figure 2: New approach for the testing process of electric powertrains

The presented results were achieved in the research project TechReaL [2]. The central idea of this project is to transfer testing from the physical, expensive vehicle prototype to the test beds of the component suppliers and service providers. The approach aims at a reduction of integration effort as well as travel and transportation expenses. Also, on tests benches, highly specialised staff can be expected to be more easily available in case of issues with individual components to be solved. The presented approach leverages the mentioned potentials for time and cost reduction.

A similar approach for the academic environment is presented by Albers, Yan and Behrendt [3] to enhance the usage of existing test beds and improve collaboration at research facilities throughout Baden-Wuerttemberg. At the Karlsruhe Institute of Technology (KIT) a connection of a driveline test bed and an engine test bed for internal combustion test beds was realized [4]. In contrast to this approach the project TechReaL focusses on an electric powertrain with wheel hub motors and additionally contains cross-company connections.

2 Conceptual design

For an efficient usage of the new testing approach the connection has to be realized for the different levels of component test beds. The connection between the test beds affects the operation level, the vehicle bus communication, and the physical signal layer. On the operation level a stable audio and video connection for efficient communication between the test beds staff at the different sites is needed. Additionally a remote access to the local systems can be added that allows quick changes and deployment of new software versions. This allows for a central command and control center, (CCC) which can be located at any site with a fast and stable network connection. Staff at the CCC integrates the components on the various test beds with the virtual car and operates the test runs, supported by the component specialists located at the test benches. The second level comprises the vehicle bus communication between the real and simulated components. On this level all the necessary bus signals for error-free operation have to be implemented. The third level includes the connection of the physical target and actual values (e.g. torque/speed, current/voltage) that are applied to or measured at the physical interfaces of the units under test.

Apart from the connection on the three levels mentioned above, the basis for any efficient integration of real vehicle components on test beds within a virtual test platform is a clear and modular structure of those components within the vehicle and environment model, as shown in Figure 3.

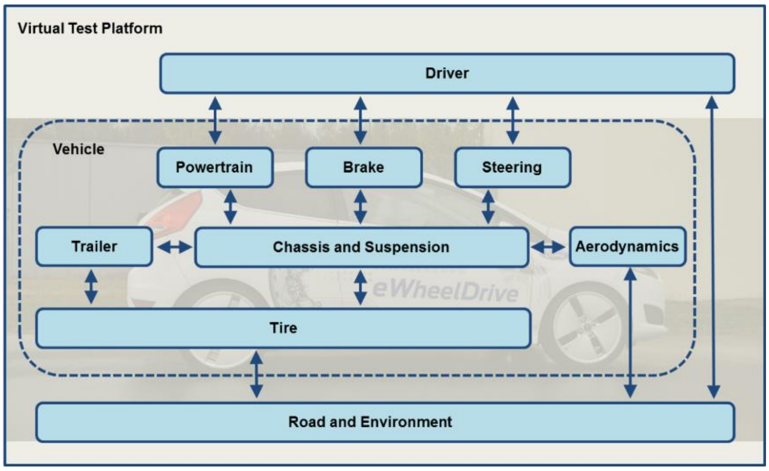

Figure 3: Modular vehicle and environment model

Each interface between vehicle components has a set of physical and/or logical signals as shown by the blue arrows in Figure 3. The set of signals consists of an array of required signals and optional signals, depending on the actual vehicle and test bed configuration. Some vehicle specific parameters might be necessary to configure those signal sets.

The real vehicle components mounted on test beds are interfacing the vehicle model implemented on a real-time system with a set of application specific I/O technologies.

3 Prototypical implementation

3.1 Network architecture

The connection between the different component test beds is realised over the internet. Every development site has its own internal network with an internet connection. The internal network is secured by a firewall and will not be accessible from outside. To connect the different sites and project partners a project network was installed using virtual private networking (VPN) technology. Every test bed is connected to the project network in real-time as shown in Figure 4.

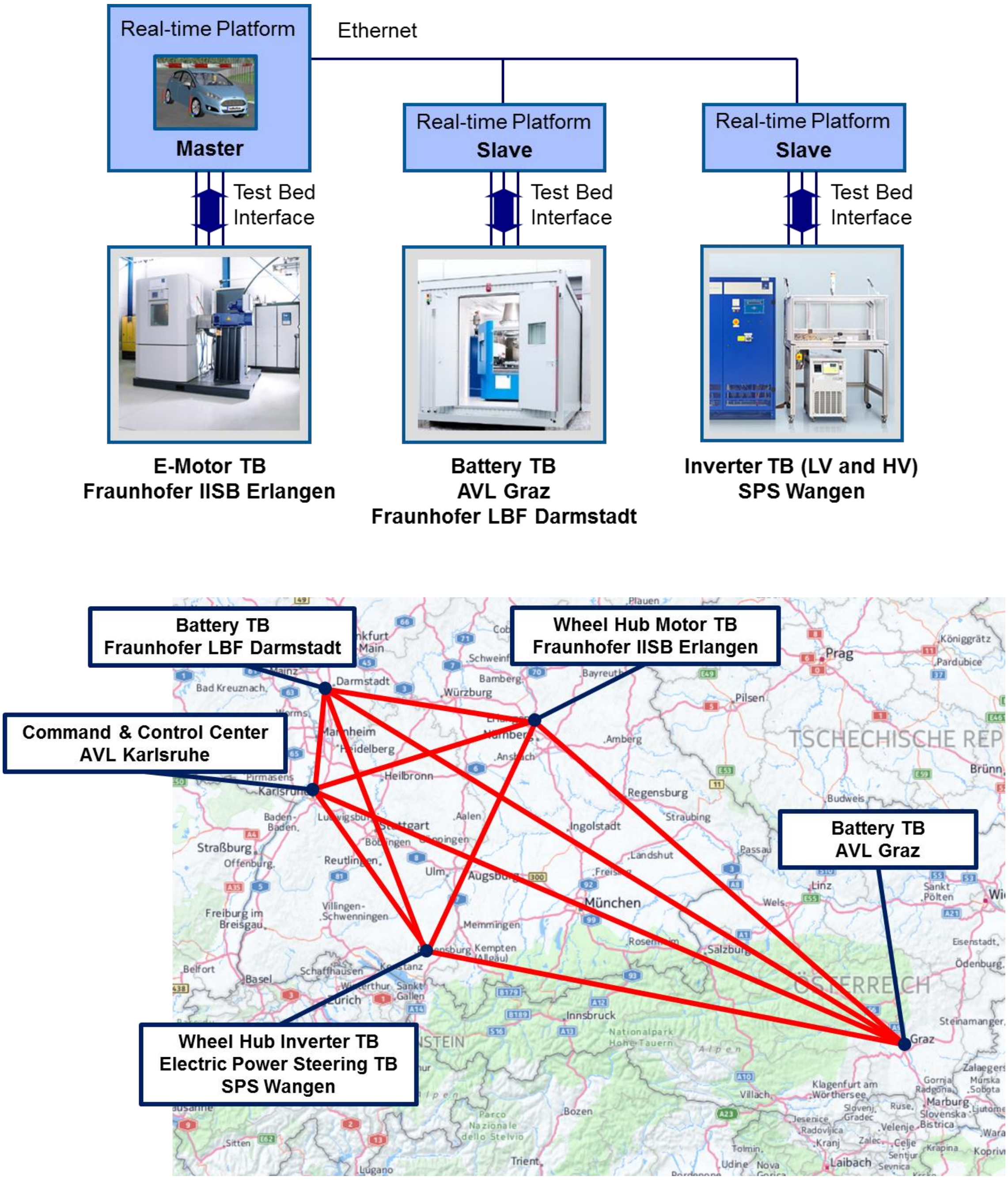

Figure 4: Implementation of test bed connections via real-time Ethernet

The implemented project network comprises three different connection types – a fast in-company connection, cross-company connection and a highly loaded in-company connection. These connection types represent the typical existing links, which can be found in today's networks.

3.2 Test bed integration

The implementation of the solution on a virtual test platform consists of three levels as shown in Figure 5:

- **Vehicle Model Level:** Contains the physical and logical signal exchange between the vehicle component models. The model manager of the used real-time platform handles the configuration and execution of all vehicle related models.
- **XMI Level:** Contains the signal mapping from the vehicle model to the I/O system and the logical handling of the test bed interface. For each connected test bed an instance of an Extended Model Interface (XMI) manager handles the states and signals of the test bed interface. The XMI is based on the FMI standard for co-simulation [5] and has been extended for the connection of test beds.
- **I/O System Level:** Contains the I/O signal exchange between the real-time platform and the connected test beds and units under test. The I/O manager of the used real-time platform handles the configuration and execution of the signal exchange.

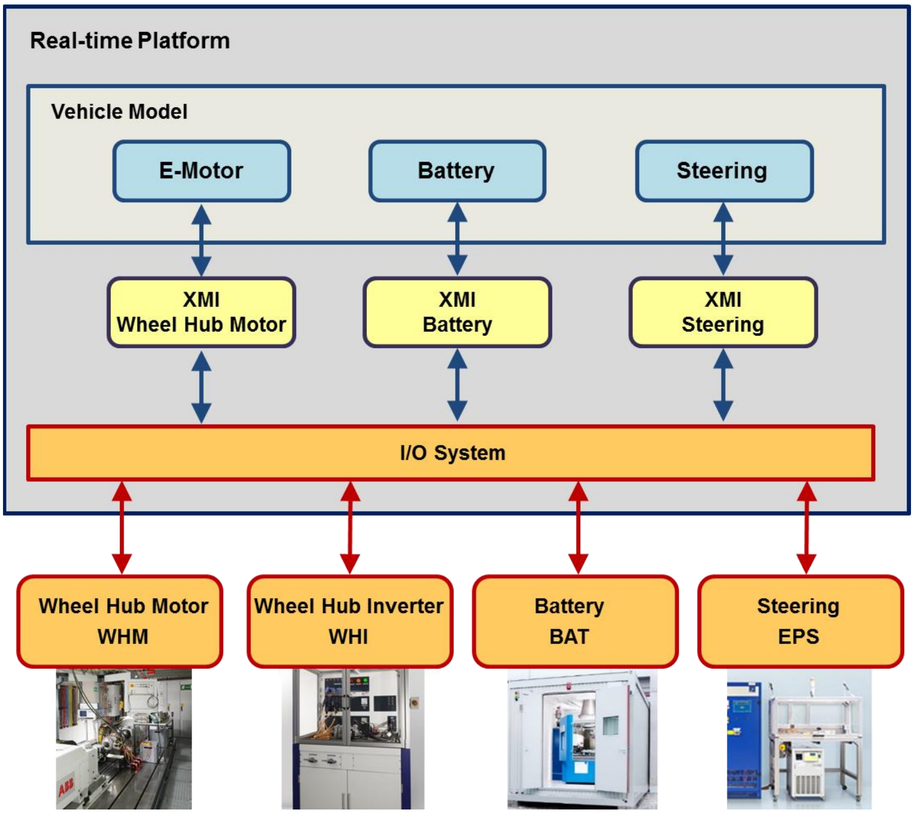

Figure 5: Structure of the test bed integration

The XMI level between the model level and the I/O System enables a flexible configuration of all available test beds in the network. It is possible to individually activate or deactivate the connection for each test bed before the test run. Therefore a test bed can be operated standalone with local simulation or connected in a distributed validation framework. Additionally the connected real test beds can be exchanged with virtual test beds for analysis of network performance and test preparation.

During the connected test bed operation either the wheel hub inverter with an emulated electric motor is integrated into the virtual vehicle or the wheel hub drive with the real electric motor and inverter.

4 Experimental results

4.1 Network performance

In order to classify the different connection types the round trip time (RTT) is measured for each dedicated connection. Figure 6 visualizes how the round trip time is measured. The master system sends out data packages periodically signed with a unique identification number. The information is then read by the slave system and the package is sent back with the same ID. On the master system side the elapsed time between transmission and reception of a data package is measured.

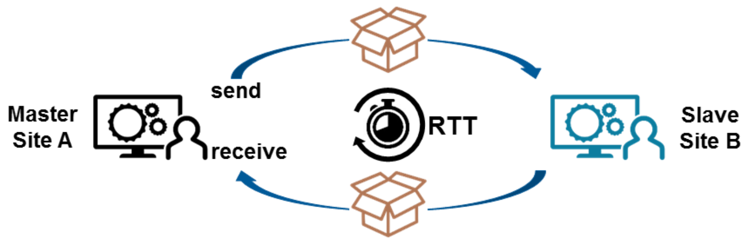

Figure 6: Measurement of Round Trip Time (RTT)

The results of these measurements are shown in the following Figures 7 and 8. The connections Wangen – Karlsruhe and Karlsruhe – Graz are in-company connections, whereas Erlangen – Graz is a cross-company connection. In cross-company connections, the quality-of-service (QoS) parameters of the data connection are not fully controllable and the data packets have to pass the firewalls at each end. Both connection properties can have a negative impact on the overall connection quality.

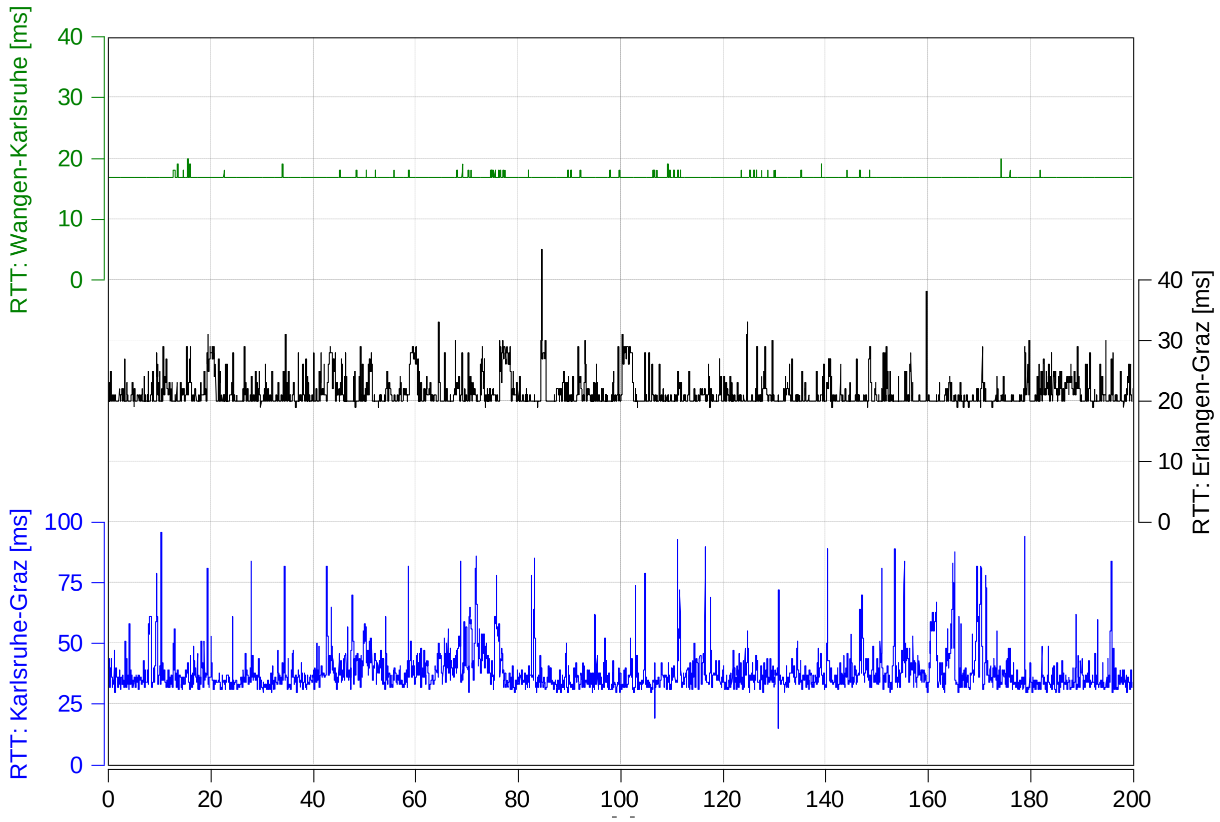

Figure 7: Measured round trip time (RTT) for three connections in the project network

The distribution of the RTT for the measured time samples of 200 s each in Figure 7 and the associated statistical quantities in Table 1 allow for a direct comparison of the connections. The connection between

Wangen and Karlsruhe shows the lowest delay time and jitter due to the high bandwidth and relatively low traffic. In contrast, the connection between Karlsruhe and Graz has a high delay time and jitter resulting from the high traffic between the sites. Although both connections are in-company connections the bandwidth and usage of these connections differ greatly. The cross-company connection between Erlangen and Graz lies in-between.

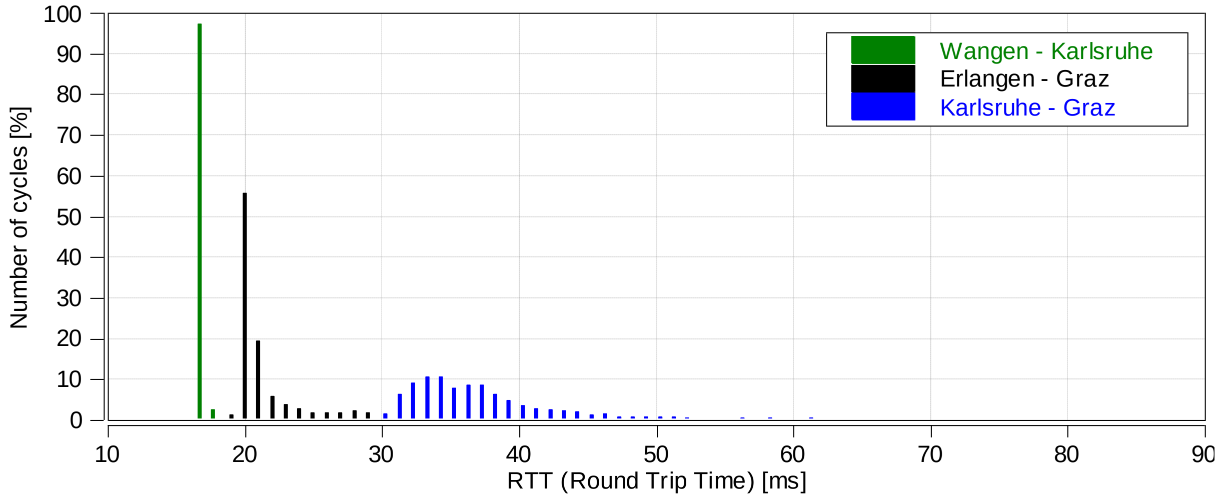

Figure 8: Distribution of Round Trip Time (RTT) for three connections in the project network

The jitter that can be described as the irregularity of the measured RTT is quantified by the standard deviation.

Table 1: Round trip time (RTT) statistical quantities

	Round Trip Time (RTT) [ms]		
	Wangen – Karlsruhe	**Erlangen – Graz**	**Karlsruhe – Graz**
Min	17	19	15
Max	20	46	96
Mean	17.0	21.4	38.2
Std	0.2	2.7	8.4

4.2 Connected manoeuvre-based testing

A standardized manoeuvre-based testing is the base for a successful test automatization and it will further ensure that test results between a real car and the results required with the new test process will be comparable. With the connecting between the test beds it is possible to compare measurements from the inverter test bed in Wangen to the electric motor test bed in Erlangen using the same battery without the inconvenience of transporting a prototype battery between the sites. Figure 9 depicts the differences in the torque and speed behaviour on the inverter and the electric motor test bed.

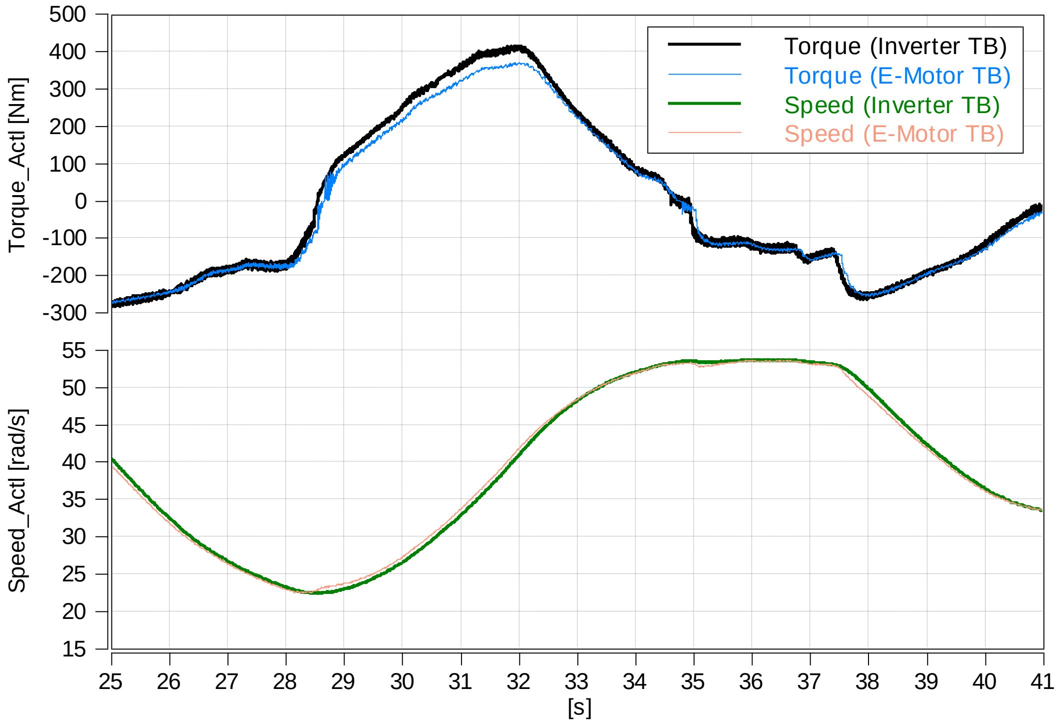

Figure 9: Comparison of torque and speed on e-motor and inverter test bed connected to battery test bed

The electric powertrain with wheel hub motors offers the possibility to enhance the vehicle's transverse dynamics by using torque vectoring. The high dynamic torque control of the individual wheel hub motors, as shown in Figure 10, causes an increased dynamic load of the vehicles components. Therefore the application of the torque vectoring has a high impact on the durability of the vehicle components. With the possibility to test the torque vectoring on system level early on with the real prototypes on highly equipped test beds weaknesses can be identified and eliminated prior to on-road-testing.

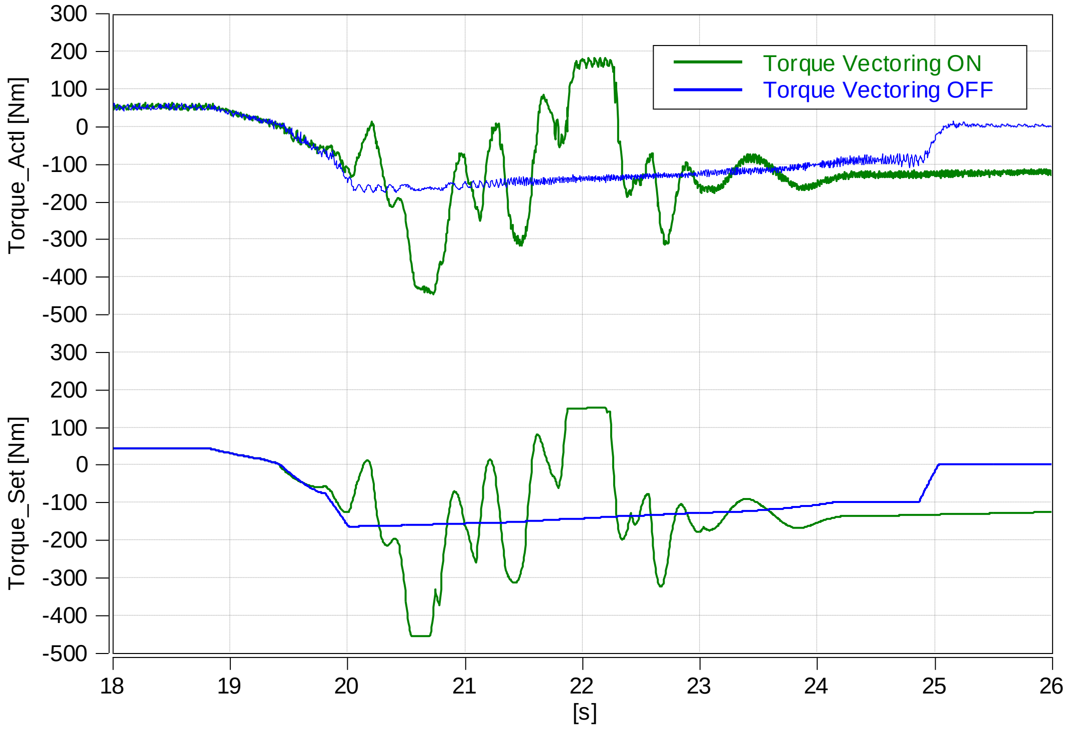

Figure 10: Increase of dynamic load on vehicle components due to torque vectoring function

5 Conclusion

The presented new testing process offers the possibility to test and validate early prototypes in an efficient manner. The approach combines the well-established Hardware-in-the-Loop method with connected component test beds inside a fully integrated virtual car. This approach enables significant time and costs reductions in the development process of electric vehicles. Furthermore is this test procedure transferable to other applications like hybrid powertrains or heavy duty vehicles. At the current stage it is possible to conduct experiments with respect to the slow dynamic behaviour of the components. The benefits of the concept like the increased efficiency due to reduced traveling effort and the possibility for the experts to stay at their component test beds are already clearly visible within the project. However due to the existing latencies in the network the prototypical implementation has to be improved regarding the coupling of the high dynamic behaviour. This is currently the focus of the research project TechReaL.

To enhance the implementation of the test bed networks the interfaces, network architecture and setup process should be standardized. This allows for an easy connection of test beds supplied by different manufacturers.

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