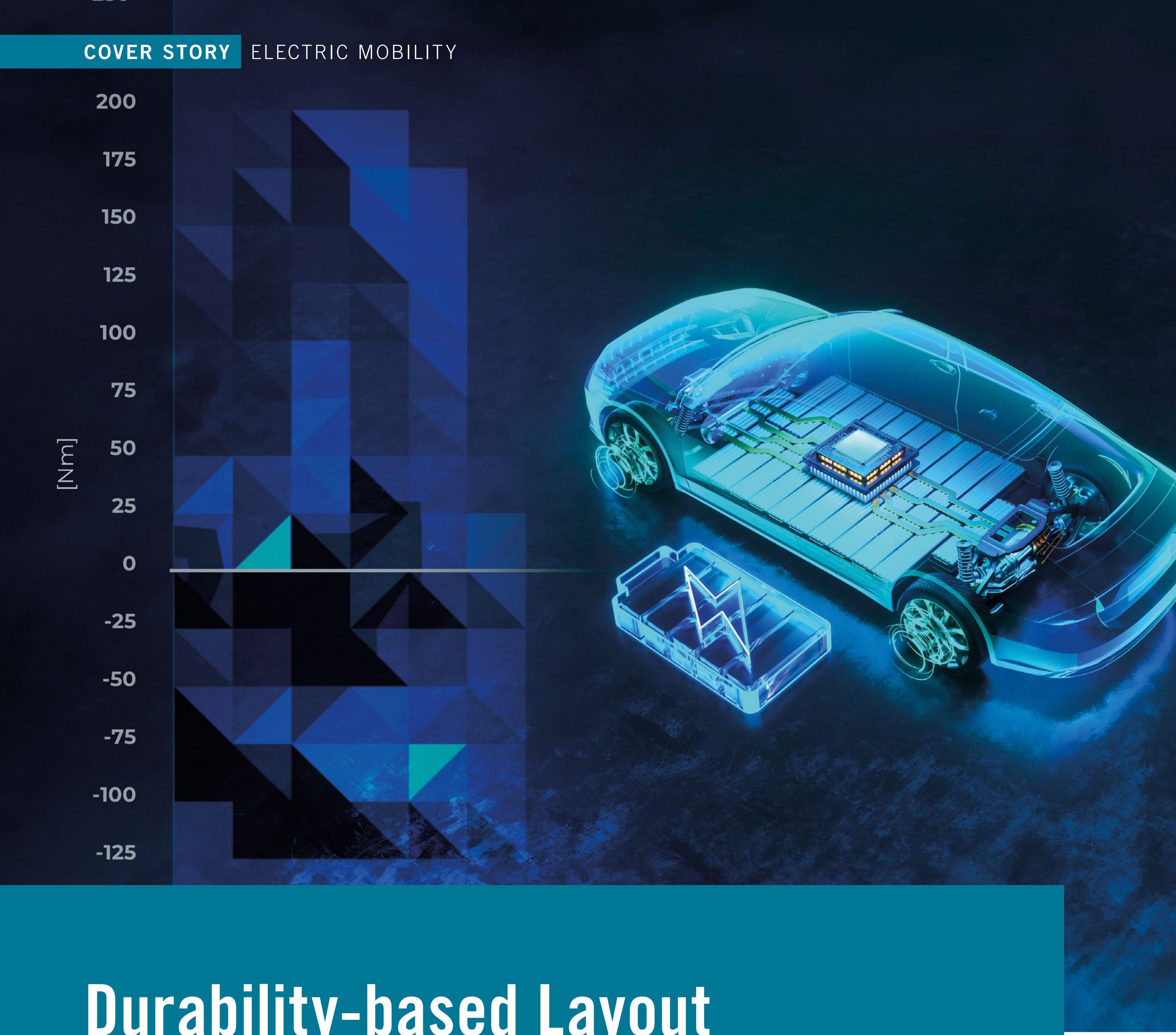
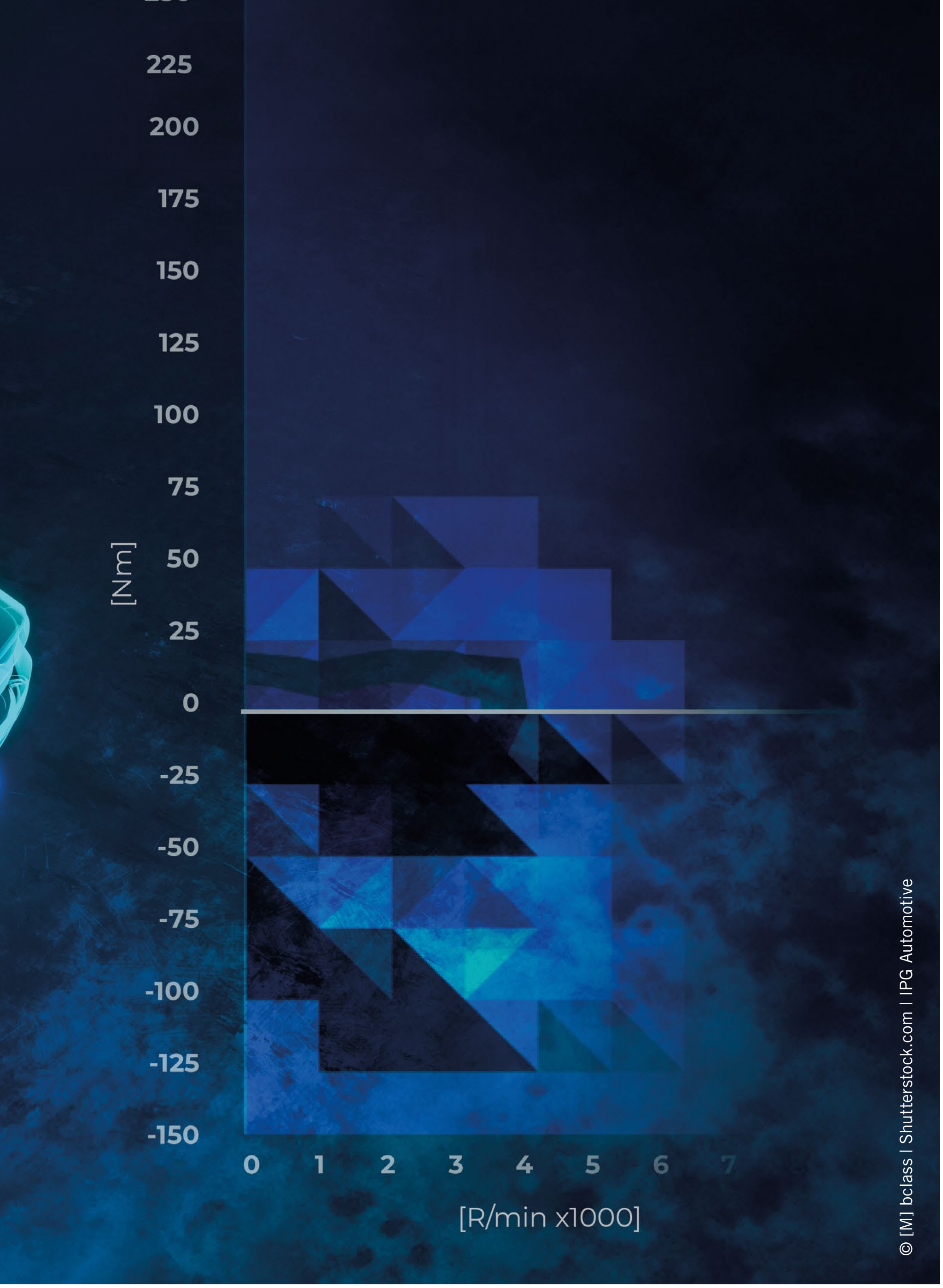


Durability-based Layout of Electric Vehicles on the Basis of Virtual Load Data

The growing demand for electric passenger cars alters the development of traction drives. IPG Automotive illustrates the impact of software and drivers on load profiles and presents a tailored calibration method. With the model-based simulation approach described, load data can be generated at overall system level without the need for physical vehicle prototypes.



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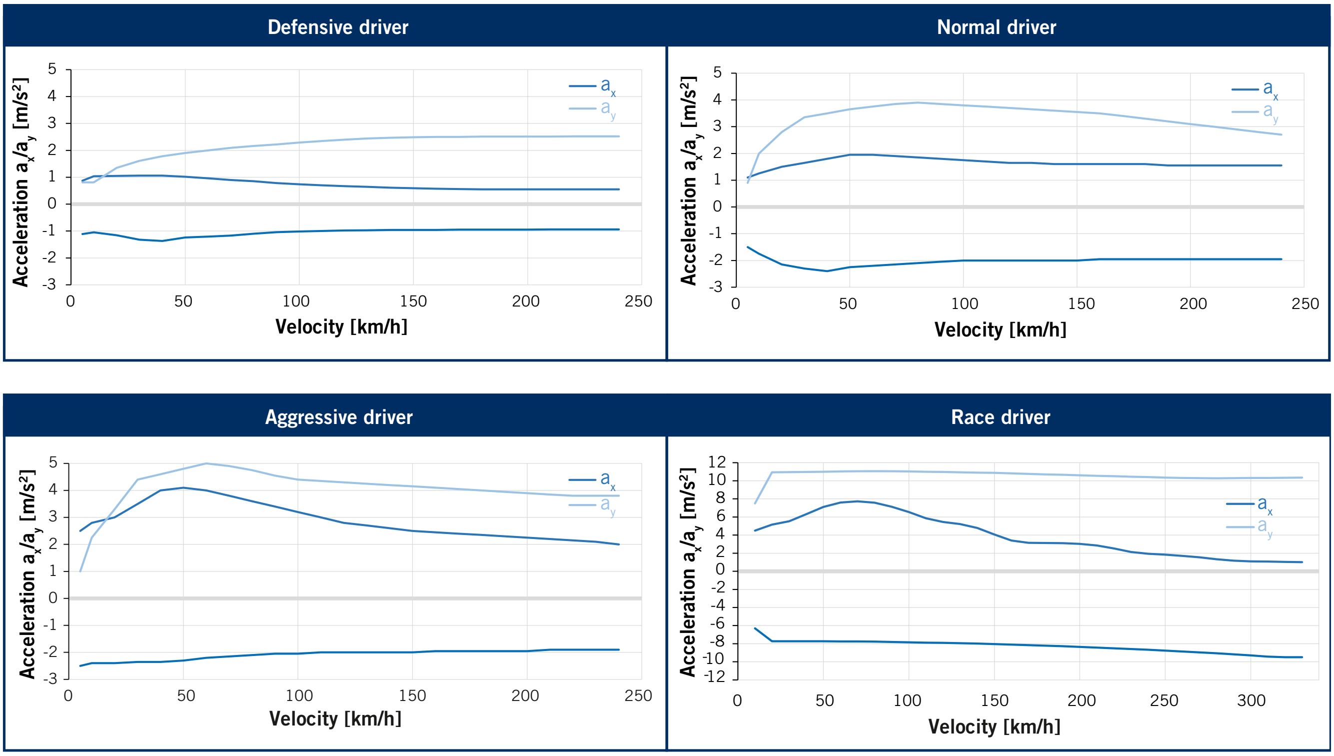
Reliability is one of the most important product characteristics and an integral part of motor vehicle quality [1]. For durability reasons, the electric powertrain requires components that are optimally geared to each other. Various challenges need to be overcome which demand critical scrutiny of existing processes and, building on this, new solution approaches.

There is for example far less or no real field data from earlier developments or from warranty data evaluation. The actually acting forces and torques in test drives (so-called load-time series) are thus often still unknown. The traditionally important experimental proof of reliability – the layout based on experience – cannot be produced.

Well-known phenomena from the realm of combustion engines such as jerking and clattering and the resulting failure phenomena as well as effects due to shifting and load change events do also not apply. At the same time, so-called drive torque ripples or cogging torques can also occur in electric motors which may have a negative impact on the durability. These phenomena are summarized under the term “toxic torque” and include all frequency shares that do not serve propulsion [2].

One focus of this technical article is on the representation of a method that the authors call Smart Durability. Therefore, damage-relevant loads are optimally distributed between front and rear drive as well as between regenerative and dissipative braking using software and an operating strategy. Calibrating the software functions for actuators in such a way that optimum lifetime, reliability, energy demand, drivability and costs are reached represents a multi-criteria optimization problem. The trends towards all-wheel drive and regenerative braking in electric mobility open new possibilities.

The control and response behavior of electric motors, which is 10 to 100 times faster than that of combustion engines,


Defensive driver

Normal driver

Aggressive driver

Race driver

FIGURE 1 Velocity-dependent acceleration limits of the four driver models (© IPG Automotive)

can also be used to actively dampen damage-relevant load peaks by means of intelligent control. A damage can be introduced into the powertrain via the tire-road contact for example when driving over a curb stone. By the same token, aggressive actuating speeds can lead to damage-relevant torque jumps or load peaks if not calibrated properly.

These special challenges in electric mobility overlap global trends, namely higher customer expectations regarding weight reduction and energy efficiency resulting in higher performance densities and thus lower reliability. This issue can only be countered with higher precision in the applied methods. As a result, reliability prediction and optimization, as made possible by test campaigns based on virtually generated reference loads, are increasingly becoming the focus of development activities in simulation.

PROCEDURE

Derivation of respective load profiles starts with planning a virtual measurement campaign which captures the occurring reference loads and operating conditions in real-world operation on a virtual vehicle prototype via virtual measurement channels. For this, the virtual (software-defined) vehicle is embedded into a virtual environment which consists of driver, road and traffic [3].

This holistic, model-based approach allows to generate meaningful, user-oriented load data distributions for global markets. It includes models for different types of drivers, vehicles, topologies, legal restrictions as well as climatic conditions, and offers high flexibility and control over variations of use. Load data and distributions as well as

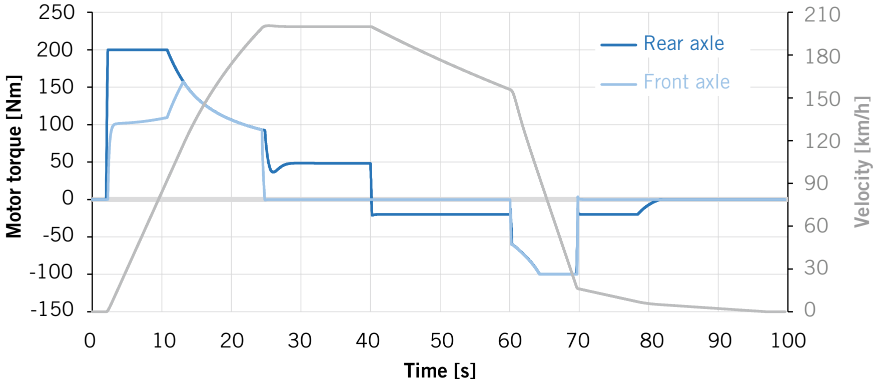


FIGURE 2 Motor torque (shades of blue) and velocity (grey) for variable torque vectoring strategies when accelerating (3 m/s²), coasting and braking (© IPG Automotive)

the associated sensitivities can be determined virtually by varying the boundary conditions and different usage profiles [4].

VEHICLE MODEL

As a key element, the presented simulation approach includes a realistic, modular, mechatronic vehicle model. This maps relevant multi-body dynamics and Smart Durability control technology (via Virtual Control Units, VCUs) for actuators (for drives and brakes). The model is parameterized consistently with the physical vehicle to plan the lifetime tests [5].

In the example discussed here with a focus on the test methodology, an electric vehicle with all-wheel drive and one motor per axle is used. The vehicle has a weight distribution of 50/50, and a brake force distribution of 2:1 (front/rear) is applied. To distribute the required total torque between front and rear axle, different motor types and Torque Vectoring Strategies (TVS) were used. This allowed to calibrate the software and hardware of the vehicle as well as to precisely model operating conditions and load distributions in virtual drive operations.

As an example, different energy recovery strategies were applied. The friction brakes of both axles were only used if the required brake torque exceeded the maximum recuperation torque of the electric motor at the respective axle. Energy recovery did not start below 12.5 km/h. The powertrain enables an electrothermal or electrochemical energy recovery as well as mixed operation. During the test drives, not only the TVS but also the driving behavior and the environment model were modified.

DRIVER MODEL

The CarMaker simulation environment from IPG Automotive offers a driver model capable to drive the virtual vehicle considering the course of the road, traffic density and a representative driving behavior. A key characteristic of the driver model is the velocity-dependent and non-linear coupled parameterization of lateral and longitudinal acceleration boundaries to adapt the parameterization for different target groups and reference populations.

For the following investigations, drivers with defensive, normal and aggressive driving behavior and additionally a race driver were parameterized, representing higher longitudinal accelerations and deceleration as well as lateral accelerations, **FIGURE 1**. In longitudinal direction, the parameterization is divided into acceleration and deceleration.

TRAFFIC MODEL

The simulation environment CarMaker offers different approaches for traffic modeling as well. For easy and clearly defined traffic situations, it makes sense to integrate traffic objects with their own trajectory into the

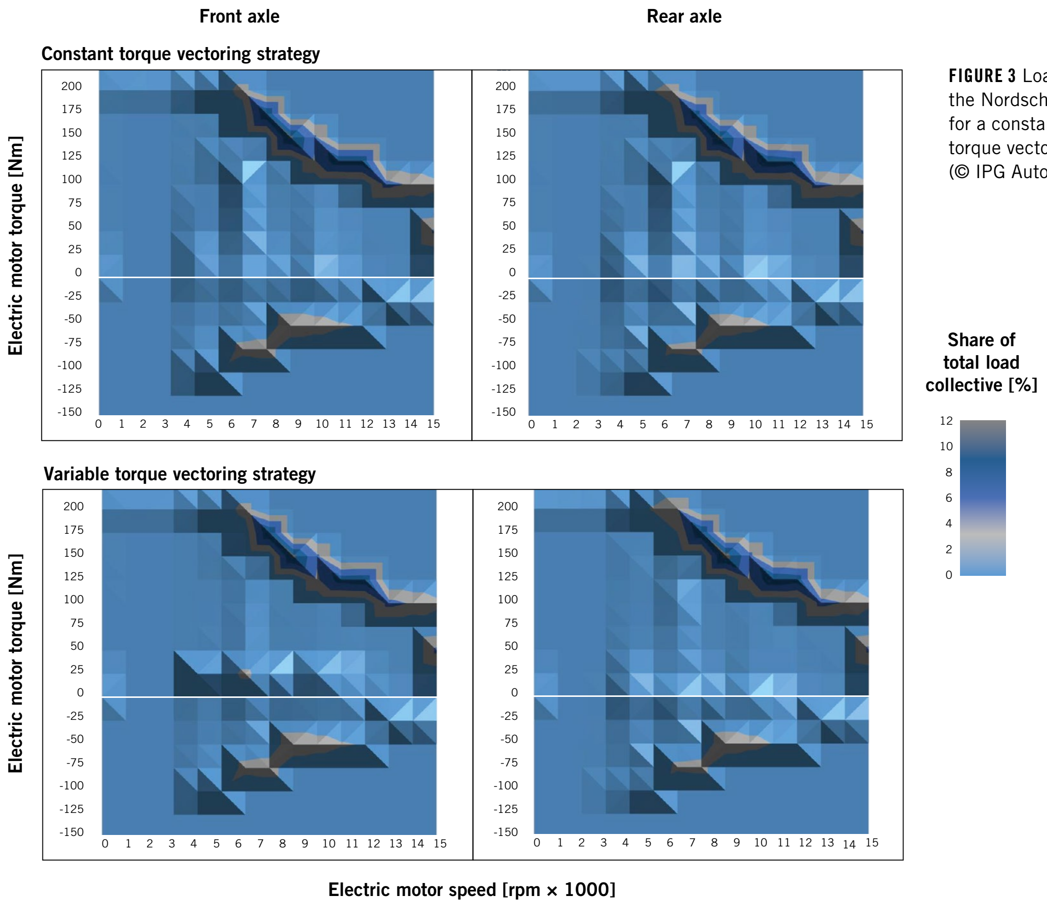


FIGURE 3 Load data distributions for the Nordschleife racetrack scenario for a constant (top) and variable torque vectoring strategy (bottom) (© IPG Automotive)

test scenario. Alternatively, they can move autonomously through the traffic.

In addition to the active calculation of traffic objects, solely their influence on the ego-vehicle can be modeled as well to limit the attainable velocity. This phenomenological approach places so-called target velocity markers on the road. Inside these boundary conditions and specifications, the driver model makes self-employed decisions about vehicle dynamics. In the example described hereafter, the modeled traffic situations were generated with velocity markers from a real driving data base. These were classified according to traffic density and route type and distributed along the digitalized route.

USE CASES

To be able to model the variations of use of the actual operating condition occurring in real-world driving in a generic way, the virtual vehicle drove on five virtual reference routes described hereafter. These include a straight route, racetrack, mountain pass road, RDE scenario and city scenario.

STRAIGHT ROUTE

To gather knowledge about the implementation of the TVS, a test was performed on a straight route. **FIGURE 2** shows the significant impact of the operating strategy on the lifetime-relevant loads.

Both motors on the front and rear axle with variable load distribution were necessary to achieve the desired total torque during acceleration. To keep a constant velocity (time point 25 to 40 s), only the rear motor was required. During subsequent coasting, solely the rear motor recuperated with very low torque. The brake pedal was actuated during the deceleration phase (from time point 60 s) which resulted in both motors to be used for a strong energy recovery. The vehicle finally costed until standstill.

RACETRACK

Before a market launch, newly developed vehicles are tested under the harshest conditions on torture tracks. A measurement campaign was performed on the Nordschleife racetrack of the Nürburgring to reproduce these tests. Due to the demanding load profile, the intelligent operating strategy adapting torque distribution between the front and rear axles had little influence on the frequency of powertrain loads and load distributions, **FIGURE 3**.

MOUNTAIN PASS ROAD

The difference in altitude on the mountain pass road Stelvio Pass with a total length of approximately 44 km is 1458 m from the start in the valley to the highest point and from there to the finish line in the next valley -1848 m. In this case study, which is predestined for brake testing, the driving behavior was additionally varied. It simulated a descent at full load with strong decelerations before hairpin bends and in compliance with the maximum admissible velocity on straights, **FIGURE 4**. The drive mode of the defensive driver and the normal driver showed a significant difference in load distribution between front and rear axle. For acceleration, the front axle was not needed as the torque of the rear axle did not exceed the threshold.

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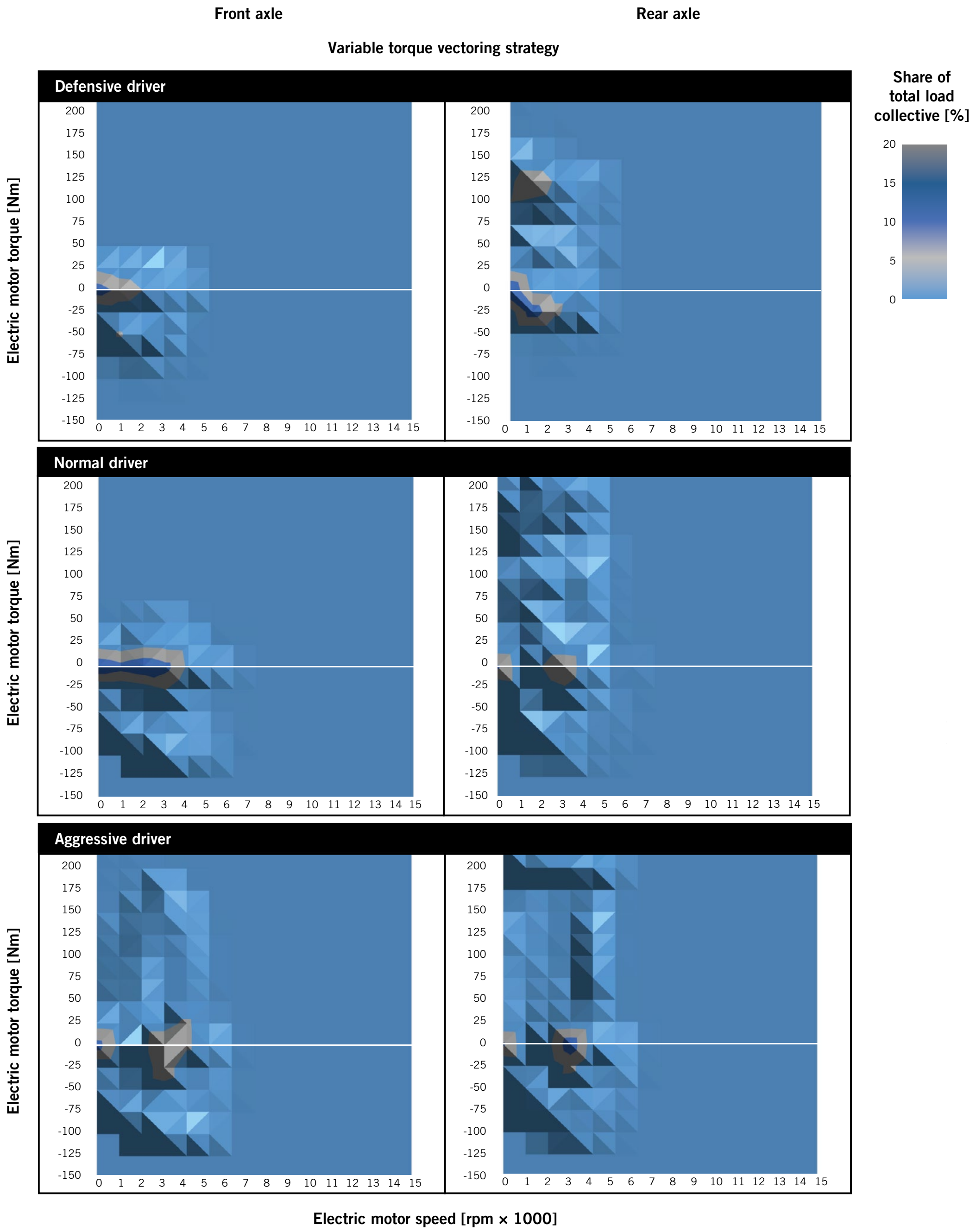

FIGURE 4 Load data distributions for variable torque vectoring strategy in the Stelvio Pass scenario with defensive (top), normal (center) and aggressive (bottom) driver (© IPG Automotive)

The front axle was thus mainly used for recovery. A portion of these positive torque load data is represented by torque values close to zero. In comparison to the defensive driver, the normal driver used a larger operating range. The aggressive driver extended this operating range even further and pushed especially the rear axle to its torque limit. In total the torque demand was higher so that the front axle had to provide considerable additional drive torque. Generally speaking, this scenario showed the strong impact of the driver have on the load data distribution of the variable TVS.

RDE SCENARIO

To evaluate the impacts of different driving modes on real driving scenarios, a measurement campaign was performed on an RDE track according to current requirements. The traffic conditions were maintained and a constant TVS was applied to focus on the impact of the driving behavior.

As the results for the front and rear axle were almost identical, **FIGURE 5** only plots the load data of the rear axle. Compared to the defensive driver, the loads increased significantly for the normal driver as well as the aggressive driver during acceleration and deceleration with higher torque values. At the same time, the share of load data with lower torque remained at a similar level.

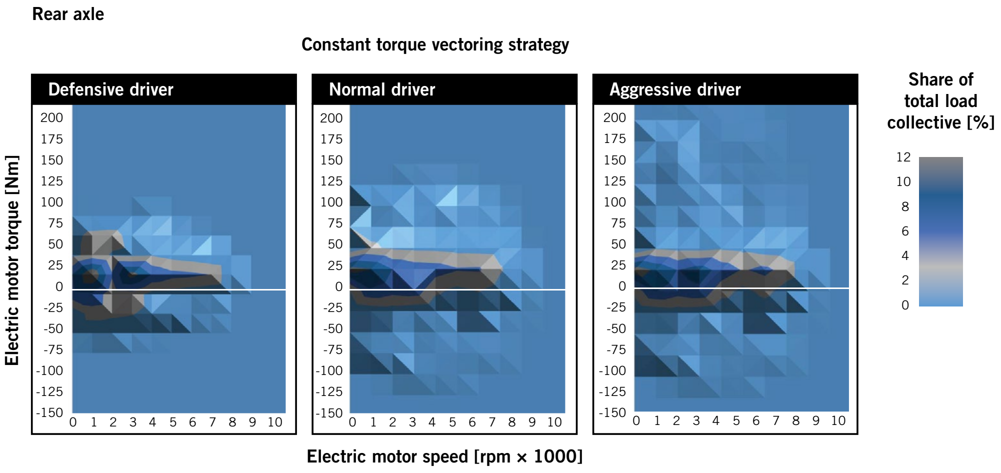

FIGURE 5 Load data distributions for the RDE test drive with constant torque vectoring strategy (© IPG Automotive)

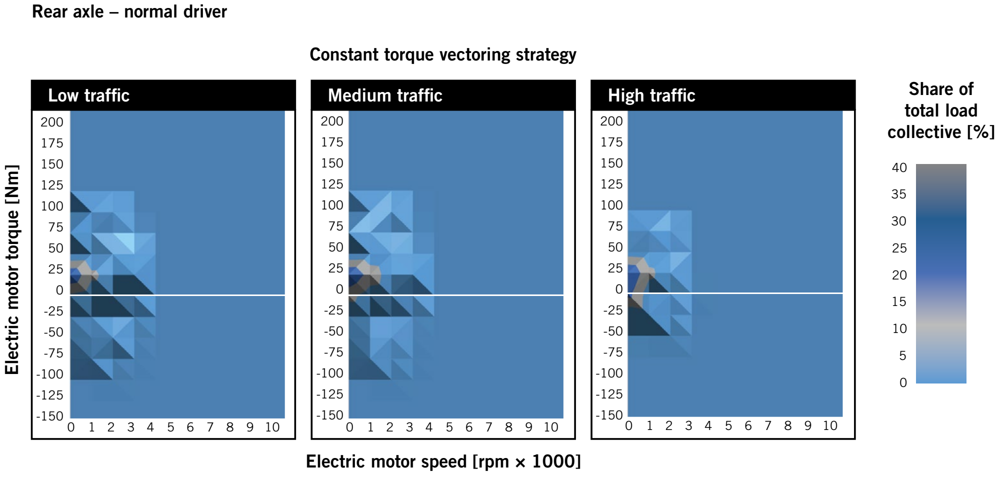

FIGURE 6 Load data distributions for city test drive for different traffic density (© IPG Automotive)

CITY SCENARIO

The city-like scenario used route sections of the RDE scenario and combined them with different traffic conditions. The total driving distance was 8.3 km. To focus on the influences from traffic, only the vehicle variant with constant the TVS was controlled by the normal driver model. As the results for the front and rear axle were almost identical, **FIGURE 6** only plots the load data of the rear axle.

In comparison with the previously mentioned investigations, the load spectrum expectably had lower speed ranges. The largest portion of load data for all driving modes was within the scope of 25 Nm and up to 2000 rpm. The difference between medium and low traffic density is small. The high traffic density results in a reduction of the characteristic map so that only load data up to 3000 rpm speed and with a maximal torque of 75 Nm were reached.

CONCLUSION

By using representative examples, IPG Automotive showed that a model-based simulation approach can generate load data on overall system level without the need of physical vehicle prototypes. The results prove that virtual measurement campaigns are a appropriate means to investigate load distributions with the aim of deducing durability layout targets.

The introduced method of Smart Durability engineering describes the control of vehicle actuators through software. The aim is to increase durability as well as to optimize lightweight design. For this, the control strategy needs to be included in the process as well. In this article it was shown that simulation is suitable to generate the load data based on it. This method can always be implemented when actuators are under-determined and thus result in degrees of freedom.

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