OPTIMIZED

Design and Construction of the Optimum Electric Powertrain

____ Effective design of electric powertrains is, today more than ever, a major focus of vehicle development. Porsche Engineering is therefore working on comprehensive simulations in many fields of electromobility.

By Adam Barák, Thorsten Böger, Torsten Dünninghaus, and Thomas Sadorf

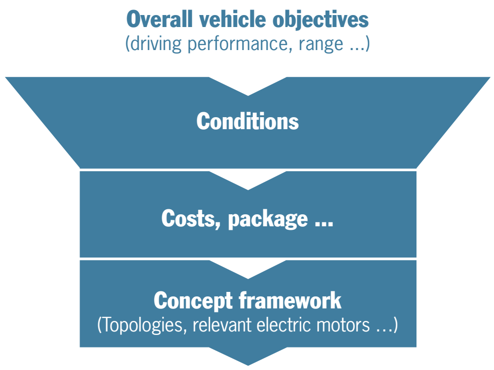
When developing vehicles with electric motors, the conceptualization and design of the powertrain is a central task. It is essential to remain focused on the specifications while optimally harmonizing the functions of the electric motor, power electronics, traction battery, and transmission components. Vehicle concepts under consideration are often highly limited by external factors. For instance, the available space may only allow a certain motor/transmission combination, the distance between axles may limit maximum gear ratios, and the use of multi-stage transmissions and clutches may not be possible.

Another limiting factor is the later production costs, which may preclude the use of highly efficient PSM (permanent magnet synchronous motor) designs from the outset. The same fate can also befall concepts with multiple gears, clutches, and multiple motors. And the time factor cannot be neglected either, because for projects with a high degree of innovation, the available time for development becomes very important. All of this leads to the question of how to best utilize the available resources to develop the best possible powertrain for the car.

Aside from project-specific factors with regard to the package and budget, targets for driving performance, consumption, and range have top priority. The most important maneuvers for determining the driving performance are full-load acceleration from 0 to 100 km/h and hill starts and ascending curbs. The set-up for consumption and range is based on target market-specific factors, legal requirements (for example in the EU the New European Driving Cycle—NEDC) and customer expectations, such as the determination of actual consumption in the CADC (Common Artemis Driving Cycles).

Topology definition

At the beginning of the development process, the target topology for the vehicle must be determined. This is a very complex task, and the result strongly depends on the vehicle type and the technical specifications. There is any number of possible arrangements and combinations of the powertrain components, each of which offers specific advantages and disadvantages. One possible layout is a topology with an electric motor on the front axle and a second one on the rear axle. In terms of propulsion, it offers the benefits of all-wheel drive and the greatest potential for recuperative braking with regard to driving stability. In this topology, it would be possible, for example, to ›



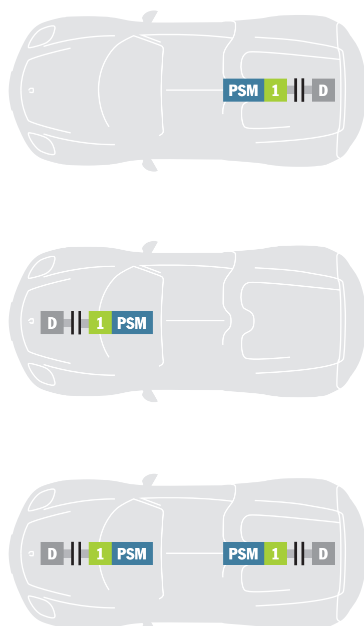
DOE plan

	CONCEPT 1 (e.g. rear-wheel drive)	CONCEPT 2 (e.g. all-wheel drive)	...
Driving cycle 1 (e.g. ARTEMIS)			
Driving cycle 2 (e.g. NEDC)			
0–60 km/h			
Hill start			
Ascending curbs			
Elasticity			

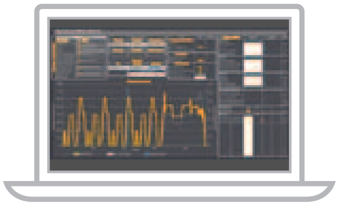
Evaluation & design review

Decision-making process for the effective design of the powertrain

Example of different topologies



Porsche Engineering Simulation Methods



eCruise

In-house Excel-based calculation program for fast preliminary assessments

AVL Cruise

Complete vehicle simulation to determine driving performance and consumption

Matlab/Simulink

Driving performance and consumption simulation in combination with complex subsystem models and rule systems

combine different motor types. One motor with optimal efficiency would assume the majority of driving situations, while a cheaper and less efficient motor would cover the required bursts of high performance. This would enable reduced costs with minimal impact on consumption.

One of the first steps is to convert the factors from the project description into technical characteristics. Here it is crucial to consider the interactions of the system components. Take this example: the desire for a long range could be fulfilled by a sufficiently large traction battery. The great weight of the battery, however, would compromise the vehicle's acceleration behavior. The costs of the larger battery, the package, and the higher energy consumption stand in opposition to numerous other factors.

Simulation of driving performance and fuel consumption

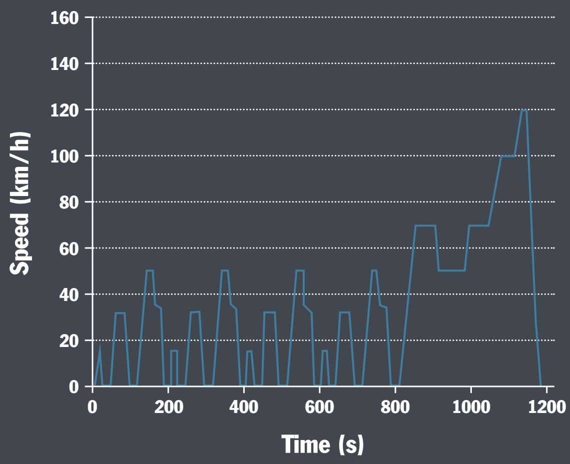
To generate ideas and ultimately decide on suitable concepts, well-known tools are brought into play, such as the morphological box and the decision matrix. Simulation of driving performance and consumption plays a significant role in determining the potential of various concepts and comparing them at the outset. The range of concepts under consideration and the components available for selection is narrowed down at this stage. To evaluate the remaining relevant powertrain concepts, the models are made more detailed at this point. In a DOE (Design of Experiment) plan, these are assessed by simulation. Once the results are in place, the individual concepts can be compared in detail and evaluated. The insights gained and tendencies observed through this process enable a finer granulation of the concepts to determine the optimal design of the powertrain.

At Porsche Engineering, the Matlab/Simulink, AVL Cruise, and eCruise programs are available for this purpose. The eCruise calculation program was developed in-house for simple and quick quantification of consumption and driving performance values in the concept phase.

Definition of the motor size

Once the topology has been defined, the next task is to determine the size and type of the electric motor(s). The minimum required driving power is determined depending on the required driving performance, the applied evaluation cycles, and the motor operating points. In the NEDC, for example, due to the low dynamic response with constant accelerations, decelerations of max. 1.4 m/s², a maximum speed of 120 km/h, and the

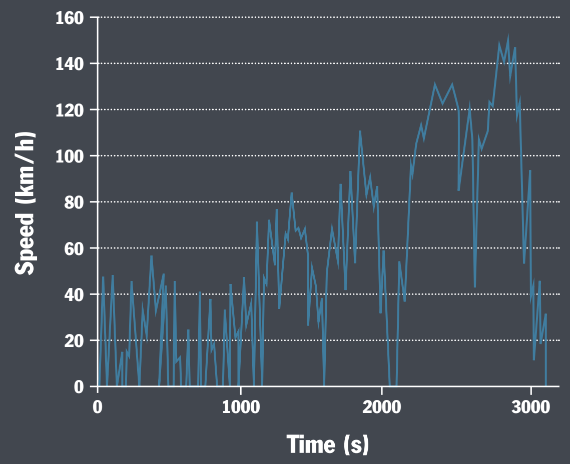
New European Driving Cycle—NEDC



The NEDC is the legally binding consumption cycle in Europe and China. It is comprised of constant speed drives, constant accelerations, braking and idling phases.

Maximum speed	120.0 km/h
Average speed	33.6 km/h
Stopping time	20.0%
Length	11 km
Maximum acceleration	1.0 m/s²
Maximum deceleration	–1.4 m/s²

Common ARTEMIS Driving Cycles—CADC

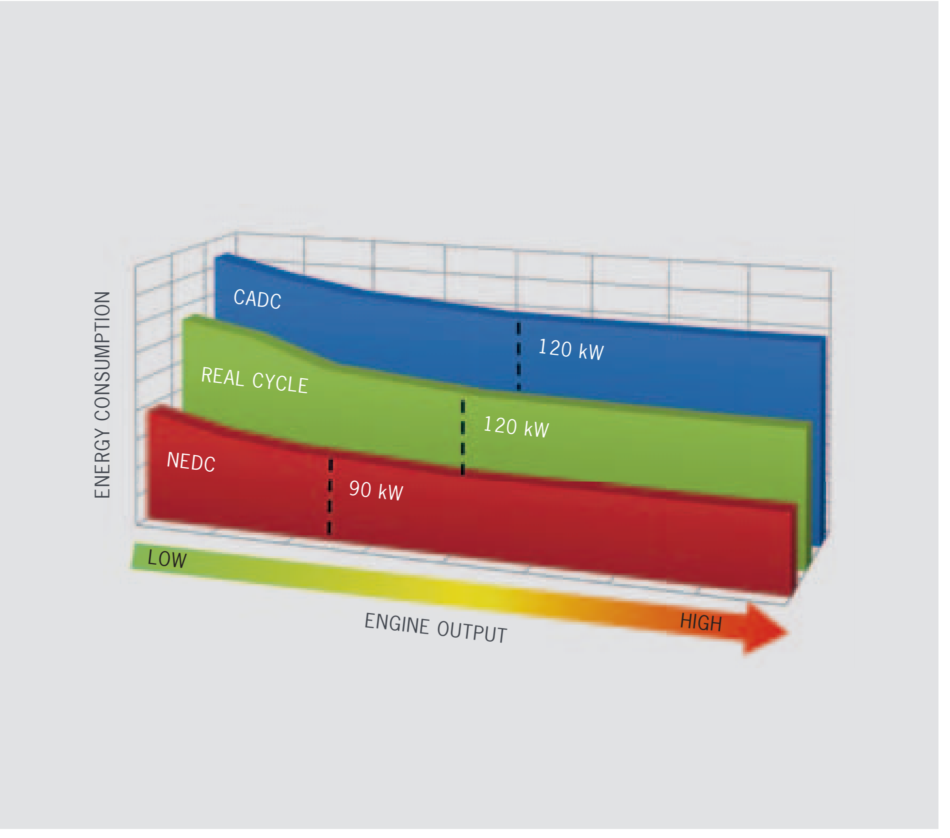


The CADC was created as part of the European research project ARTEMIS. The cycle is distinctive in that it is derived from real driving profiles.

Maximum speed	150.4 km/h
Average speed	59.2 km/h
Stopping time	9,7%
Length	51.7 km
Maximum acceleration	2.3 m/s²
Maximum deceleration	–3.6 m/s²

many constant speed drives, less driving power is required and relatively little energy consumed. Thus the motor is frequently operated in the low power range in the cycle. Electric motors with high efficiency and low power are advantageous here.

By comparison, a dynamic cycle such as the CADC has higher accelerations and decelerations of up to 3.6 m/s². In addition, the maximum speed is 150 km/h and there is hardly any constant speed driving to speak of. As a result, the cycle taps a larger power range of the electric motor. For a low cycle consumption, the efficiency must be high for a wide range of the performance map. Moreover, in a dynamic cycle, higher power is not just required briefly (recuperation braking) but over long phases. If the motor has insufficient power, not all of the energy can be recuperated during braking and the motor goes into thermal overload more quickly. The motor control then goes into derating mode. For the duration of a defined cooling phase, the available motor output is reduced. The greater the thermal mass of the motor and ›



Impact of motor size on energy consumption in the different driving cycles

the greater the power, the less often the vehicle will go into the derating range. This too speaks in favor of a minimum motor size in the design of a credible electric powertrain concept.

Impact of recuperative braking

Larger motors in combination with suitable transmission ratios provide additional benefits during recuperative braking. In a conventional vehicle, the kinetic energy is converted into heat through the friction brake and emitted into the environment without being used. Electric vehicles can recuperate a large portion of their kinetic energy. During braking, the electric motor switches into generator mode, converts the kinetic energy into electric energy, and stores it in the high-voltage battery. The amount of braking energy that can be recuperated depends primarily on the motor power, the transmission ratio, and the recuperation capacity of the brake management. Since the traction on the rear axle is limited early when braking through a corner, for example, it is advantageous to distribute the electric braking force between the front and rear axles to exploit the maximum potential of recuperative braking.

Definition of the transmission ratio

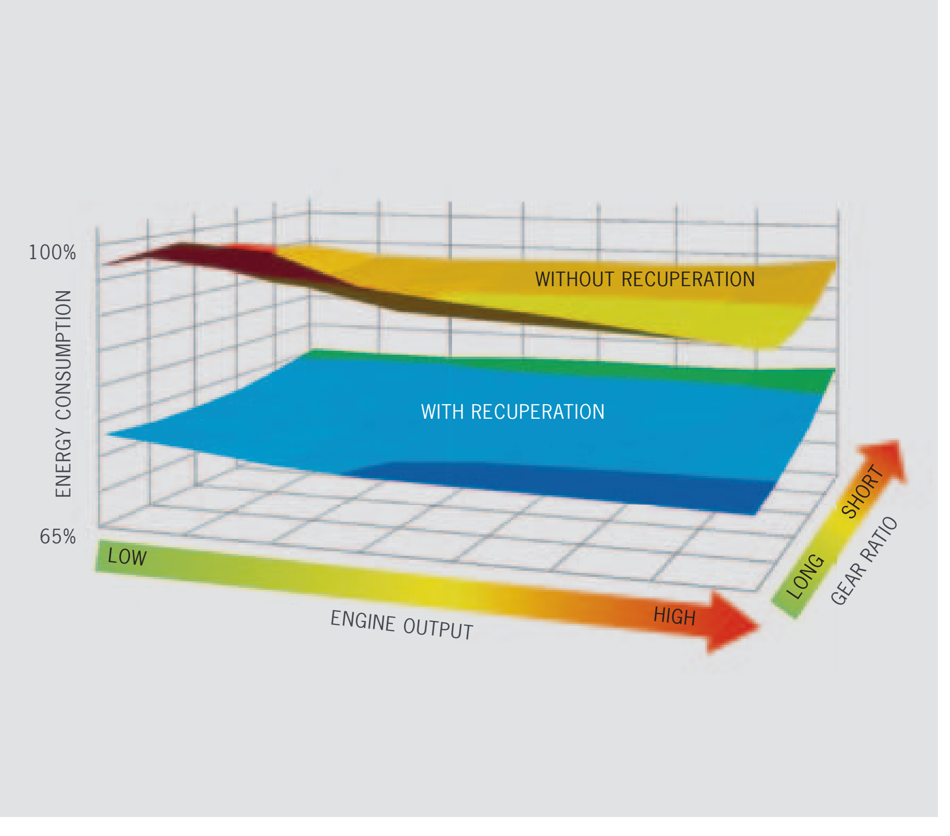
If a transmission with just one gear ratio is planned for a topology, this ratio is always a compromise between optimal power transmission, the lowest possible consumption, and top speed.

The transmission ratio defines the speed of the motor in relation to the wheel speed and how much motor torque is required for a defined acceleration of the vehicle. Since the efficiency of an electric motor is dependent on the torque and the motor speed, a given transmission ratio leads to a certain efficiency of the motor in a driving cycle. A vehicle with a long gear ratio will, assuming sufficient power, achieve worse acceleration values but also a higher top speed. With a short gear ratio, the situation is the converse.

Since the three objectives (acceleration, consumption, and top speed) may require different gear ratios, multiple-gear transmissions may present a solution. These make it possible to improve the driving performance and motor operating point distribution. But here, too, an overall system view is very important as more complex transmissions tend to be less efficient, reducing the benefit. Whether the use of multi-speed transmissions makes sense must be evaluated on a case-by-case basis in view of the project objectives.

Conclusion

The challenges with regard to electrification of the powertrain are manifold. New motor and battery concepts are being developed, and also their complex control systems and integration into vehicles have to be refined all the time. This in turn continually confronts engineers with new challenges to overcome with flexible thinking and ingenuity. For years, Porsche Engineering has been mastering these challenges successfully in a diverse array of projects. ■



Energy savings in the CADC through recuperation