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Optimizing and De-risking the Selection of Electric Drives

The right powertrain selection is critical to the automotive industry's transition to electric mobility. The Electrified Powertrain Optimization Process from Drive System Design reduces the risk at the initial stages by simulating thousands of configurations quickly to help identify the optimal powertrain, and with verifiable accuracy.

Against the backdrop of a demanding and constantly-evolving regulatory landscape, automobile manufacturers have been tasked with transitioning away from the tried and trusted technologies of the last hundred years to a vehicle world propelled by entirely new electric drive platforms. To achieve this, OEMs and tier-1 suppliers must develop new technologies, components and architectures, as well as modules for the integration and power distribution that bind these new sub-systems together.

Often this involves establishing new material supply chains while navigating volatile geopolitical sensitivities. Vast investments must be made, just as revenues from conventionally-fueled vehicles face a legislated decline while a global semiconductor shortage creates ongoing

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disruptions. "Backing the wrong horse" can leave an OEM exposed to capricious material prices and supply chain difficulties, or overly-invested in an evolutionary dead-end.

The traditional software tools and processes used to design and optimize powertrains have not necessarily kept pace with new technologies or changing industry circumstances. They remain time consuming, are easily influenced by subjective views, and are often built on conventional combustion-engine architectures – an approach that fails to take advantage of key benefits and flexibilities available within a fully electrified design.

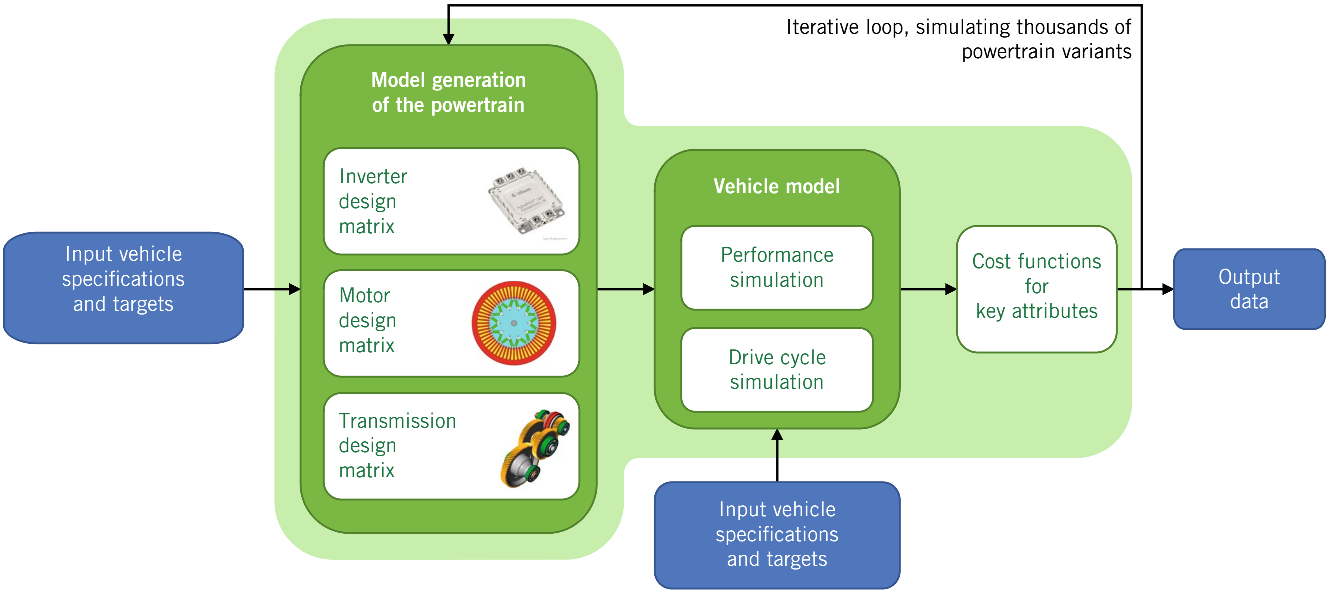
Developing an electric powertrain as a whole – a unified system with components selected and optimized to work in harmony with one another – is the only way to ensure the complex interplay between components and subsystems can be considered as part of the solution, rather than a series of individual problems that remain to be solved. For example, specifying an expensive but highly energy-efficient vehicle propulsion motor may seem counter-intuitive on a simple cost/benefit analysis, but that may open the door to the use of a smaller, cheaper, and lighter battery with a reduced capacity that lowers the overall vehicle cost, while still achieving the required range.

CONSIDERATION OF REAL-WORLD ISSUES

Experience gained over more than ten years of delivering electrified powertrain programs grants engineering services provider Drive System Design (DSD) valuable insight into the challenges faced by OEMs and Tier-1 suppliers. Developed specifically to capitalize on that experience, the Electrified Powertrain Optimization Process (ePOP), **FIGURE 1**, is a software tool created in-house to consider real-world issues such as range and energy efficiency during the early stages of powertrain design, whether for an individual component or a family of systems across a range of markets.

The process enables the mapping and exploration of a large number of prospective powertrain options within a given design space. By generating thousands of powertrain combinations, taking into account parameters such as mass, aerodynamic coefficients, and performance targets, the complex relationships between sub-systems can be exhaustively analyzed. Each combination includes the necessary data for a thorough simulation determined over a range of drive cycles, with the results compared through intelligent trade-off algorithms against the required parameters, such as performance or vehicle range.

FIGURE 1 Overview of the ePOP simulation process with powertrain and vehicle model (© Drive System Design)



Because the process is entirely objective, it can lead to configurations that might not have been considered otherwise. And by allowing greater numbers of powertrain permutations to be analyzed, these can be fully explored in ways that have not been possible before.

A post-processing interface permits drilling-down through the results to quickly establish where the most enticing opportunities lie – and to do so in a fraction of the time normally required. By assessing the output results against multiple criteria, such as cost or energy demand, it becomes clear which are the prime candidates to take forward. Combining this information with learned experience and existing knowledge helps narrow in on the optimal solution for the required objectives, significantly shortening the innovation stage of powertrain development.

No.	Correlation step	Complete WLTP energy demand error
1	Baseline ePOP – no modifications	3.22 %
2	Transmission calibrated	0.90 %
3	Transmission, motor, inverter fine-tuned	0.25 %

TABLE 1 Achieved correlation of simulation and real test: at the outset (No. 1), with transmission-only optimization (No. 2), and after final fine-tuning (No. 3) including motor and inverter optimization (© Drive System Design)

ADDITIONAL BENEFITS

Because a broad range of configurations can be assessed in the ePOP tool within the same design space, it is possible to identify trends that arise in attempting to meet the required objectives. For example, multi-speed transmissions deliver greater flexibility, particularly for heavier vehicles. The high cost of today's battery technology currently points to investing in efficient drive modules to attain a given vehicle range rather than specifying a larger battery pack. However, as battery costs change and the economics are revised, the optimal solution may alter to favor an alternative configuration. Performing this analysis at the very earliest concept stages, before the project has been fully defined, can reduce much of the initial risk and deliver confidence in the selected strategy, leading to reduced development costs and a reduced time-to-market for the eventual product.

For solutions that rely on future technologies, the process permits the forecasting of the economically viable tipping point, and which applications are likely to benefit the most. This enables development to begin ahead of time such that when the economic situation improves, the products have a head start in the market.

The process further enables tier-1 automotive suppliers to assess their products against a vehicle manufacturer's requirements to determine their

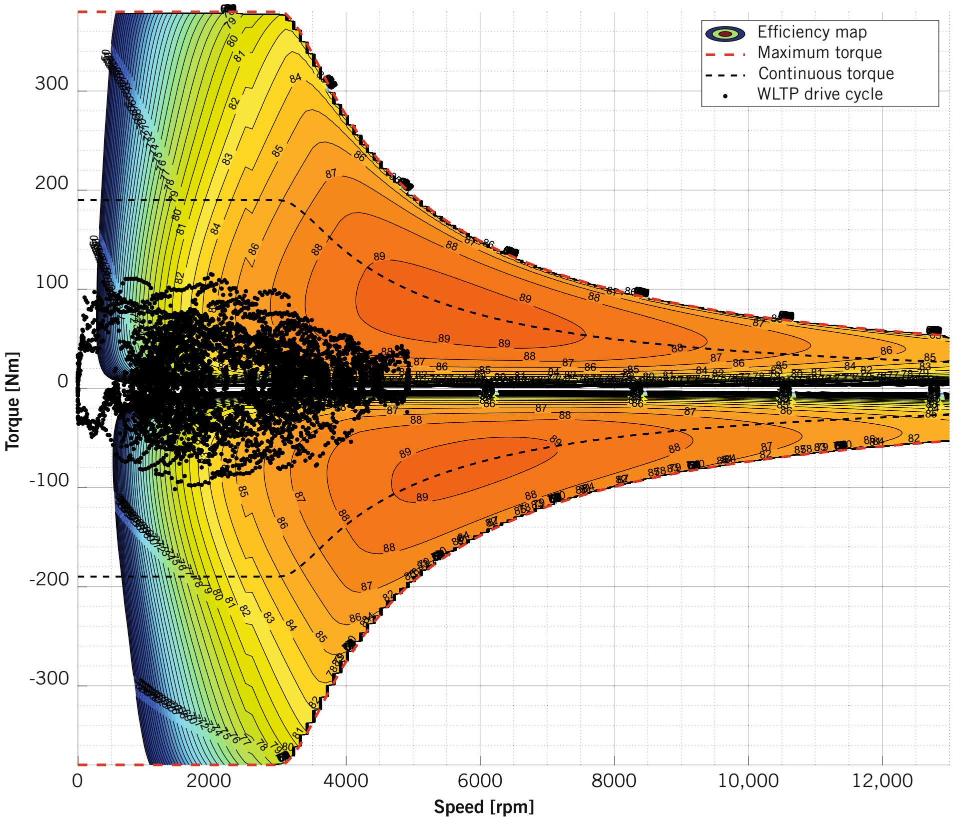


FIGURE 2 Combined plot of the motor operating point on system level (© Drive System Design)

competitiveness or, indeed, identify whether an opportunity exists for further development to achieve a better match. In addition, the process can help develop understanding across disciplines by quantifying the relative benefit or penalty of an integration solution on the powertrain as a whole, ultimately leading to a decision that is demonstrably better for the entire vehicle platform.

INTEGRATION INTO A SINGLE ASSEMBLY

The Advanced Cooling and Control of High Speed e-Drive (ACeDrive) is a collaboration between DSD, GKN Automotive, and the University of Nottingham, backed by the Advanced Propulsion Centre (APC). It aims to develop the world's lightest and most efficient electric vehicle powertrain for the volume market. By adopting new concepts of cooling and system integration, with a significant reduction in the number and size of components, the collaboration targets a 25-% reduction in packaging size and cost, a 20-% drop in weight, and a 10-% efficiency increase over current solutions.

The project results in a downsized motor, optimized transmission, and power-efficient inverter integrated into a single assembly, helping to achieve the required packaging reduction. Fewer mechanical and electrical interfaces reduce loses, while efficient silicon carbide Mosfets in the inverter lead to system-level savings.

Within the ACeDrive project, the ePOP tool has been used to consider a wide range of topology options in the inverter, motor, and transmission to ensure clarity of progression by identifying the most promising avenues for further study. To be of maximum value, the tool must deliver results with a consistently high level of accuracy when measured against data generated in the real world.

A recent test program saw Worldwide Harmonized Light Vehicle Test Procedure (WLTP) energy demand predictions for a premium battery electric SUV correlated with real test data generated by the collaboration project partner, GKN Automotive. The data is intended to form a baseline for later comparison with a prototype drive unit, but it also presents an opportunity to analyze the accuracy of the simulation process. In fact, the initial modellings were found to be accurate to within 3.22 %, while fine-tuning brought that to 0.25 %, **TABLE 1**.

REAL-WORLD TEST ENVIRONMENT AND COMPUTER SIMULATION

Testing was conducted at the Horiba Mira Advanced Emissions Test Centre in Warwickshire (United Kingdom), using the CWT One climatic wind tunnel with a four-wheel-drive chassis dynamometer rated to 150 kW power per axle of the Jaguar I-Pace test vehicle, Title Figure. WLTP drive cycle data was recorded for each axle and the energy demand calculated.

The vehicle model was populated with information for overall vehicle mass, wheel and tire sizes, drag coefficient and frontal area. Rolling resistance was characterized by vehicle speed versus drag force measured on the chassis dyno. The MotorCAD program provided the efficiency map for the motor, the Masta CAE software provided the map for the transmission, plus ePOP's inverter loss model, combining the power module losses with the motor efficiency map.

RESULTS

Both the physical vehicle and the simulation were subjected to the WLTP drive cycle, with power losses calculated at each point within the motor, transmission and inverter. A combined plot, **FIGURE 2**, provides perspective on the variation of motor operating point during the WLTP drive cycle with respect to the efficiency map. The results demonstrate that the correlation between the ePOP simulation and the real-world data for the total cumulative energy expended was initially within 3.22 %, **TABLE 1**.

By directly comparing the vehicle and simulation data, small discrepancies can be identified at various points of the cycle, **FIGURE 3**. At an enlarged scale, as presented in **FIGURE 4**, discrepancies can

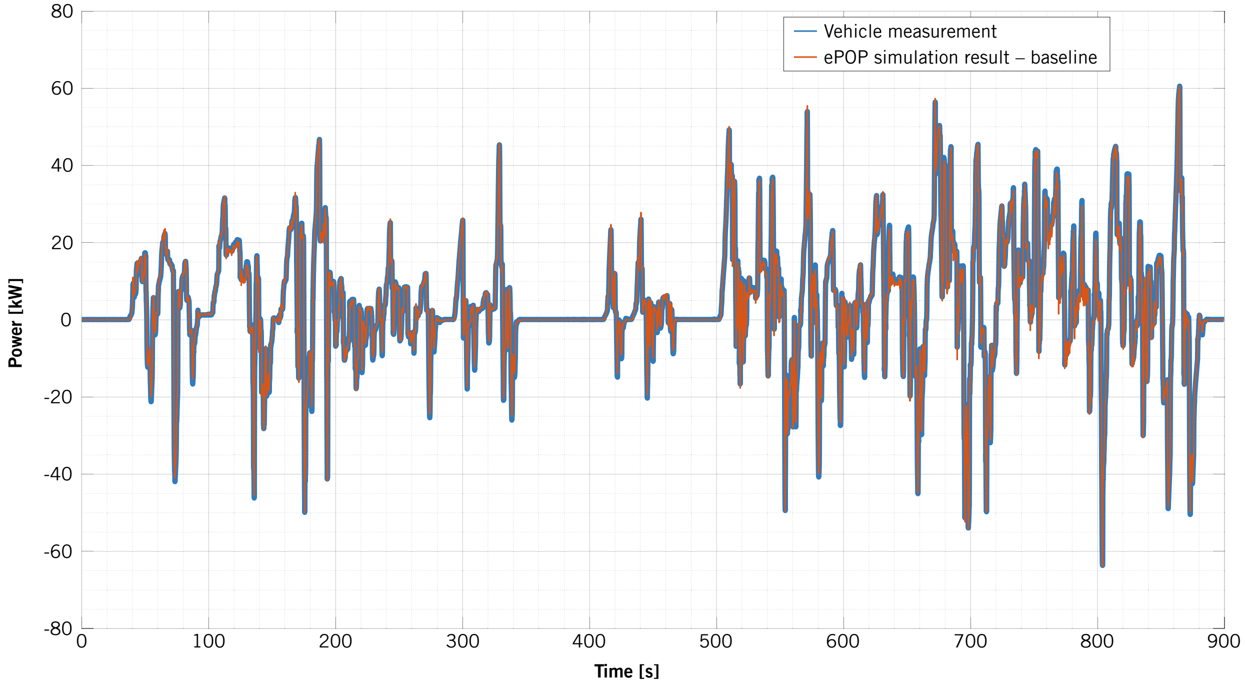


FIGURE 3 Initial comparison of baseline ePOP simulation results and vehicle measurements: overall view of the whole WLTP cycle – good correlation between vehicle measurement and baseline simulation (© Drive System Design)

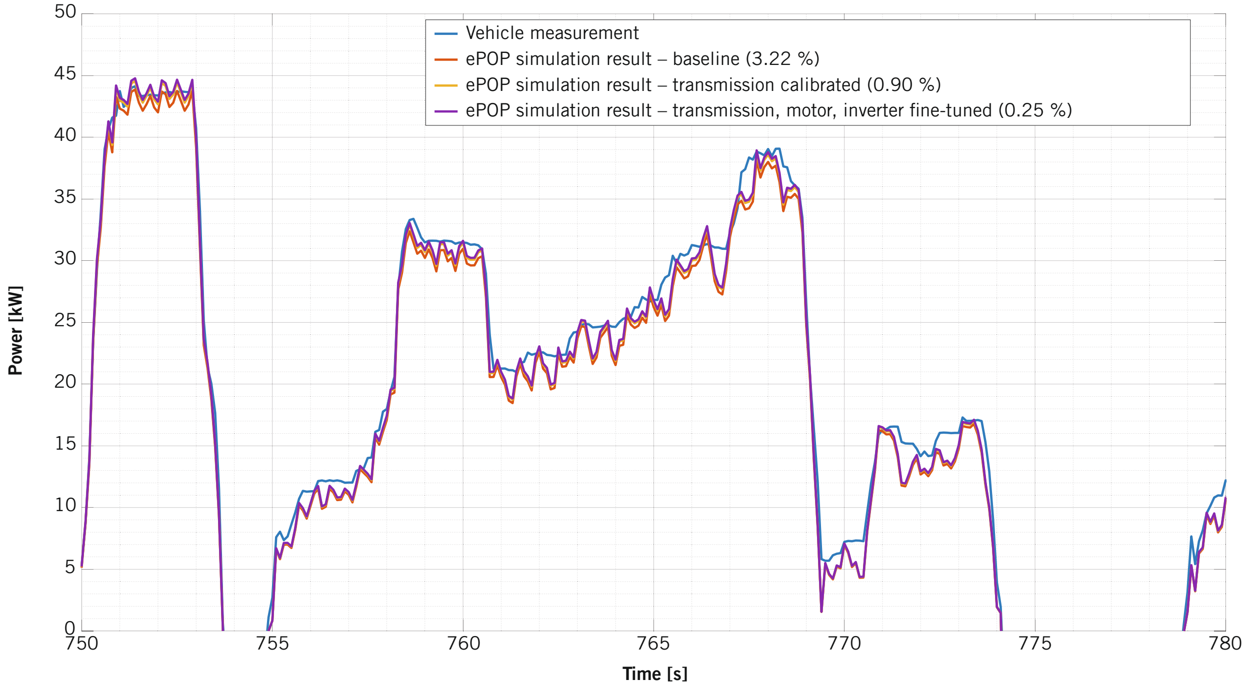


FIGURE 4 Close up view showing discrepancy between baseline simulation results and vehicle measurements and subsequent correlation improvements made by adjusting the efficiency maps of the transmission and then the motor and inverter (© Drive System Design)

be clearly seen at points corresponding to higher speeds, with much of it attributed to the contribution of the transmission efficiency alone. Engineering experience combined with knowledge regarding the limits of the factors included in the modelling led to the hypothesis that a significant portion of this was likely caused by churning of the lubricant within the transmission. By modifying the assumptions in the transmission model to include a closer representation of those loses, the simulation to measurement correlation was improved from 3.22 to 0.90 %.

Furthermore, motor efficiency was observed to be reduced at speeds higher than 2800/min. Again, experience suggested this was potentially at least partially attributable to windage, the effect of air resistance experienced by the rotor within the confined housing of the motor. By accounting for this and other high-speed losses within the motor model, the correlation was further improved to 0.25 %, **TABLE 1**.

CONCLUSIONS AND OUTLOOK

Since key strategic decisions regarding the optimal powertrain architecture can often come down to small percentage point differences, it is important that the data being considered should provide an accurate picture of the relative costs and benefits – both financial and in performance terms – of each configuration. As Drive System Design could demonstrate here, the ePOP process can deliver valuable assessments of critical factors such as efficiency and cost in high accuracy when considering the trade-offs between powertrain designs, even in its initial configuration. With modest revisions, that accuracy improved from 3.22 to 0.25 % – a level that can instill confidence in the chosen architecture that can also lead to reduced development effort and costs, and a compressed and more rapid time-to-market.

Many of the lessons learned in this program can be applied to future projects, for example enhancing the complexity of modelling scenarios to account for additional factors and losses such as lubricant churning and rotor windage. Although rising complexity can lead to extended simulation and computing times, this is countered by ePOP's ability to clearly signal at an early stage which powertrain configurations are worthy of further analysis, with the designs refined prior to making a final concept selection.