Siemens PLM Software

Design challenges and opportunities for electric powertrain with vehicle autonomy

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Introduction

By 2030, nearly 25 percent of all miles driven in the United States could be in shared autonomous electric vehicles, as per a recent study by the Boston Consulting Group[1]. The majority of autonomous vehicles announced by automakers or that are in fleet testing have electric powertrains (if not full electric, then hybridized). An electric powertrain is indispensable for autonomous vehicles because of higher fuel efficiency and reduced CO_2 emissions. It is an easier platform to support drive-by-wire systems needed for vehicle autonomy; and, as battery prices keep dropping sharply, electric is an attractive proposition because of lower cost of ownership and maintenance, especially for fleet owners in a ride-sharing ecosystem.

However, the integration of vehicle autonomy with electrification is not a matter of simple plug-and-play manufacturing. It has its challenges, and these issues need to be taken into account from the earliest design/conceptualization phase for an autonomous electric vehicle. For starters, auxiliary power demand from the significant increase in vehicle electronics can reduce electric drive range. In this article, we will highlight some of the key new challenges and unique cost reduction and optimization opportunities that come with using electric powertrains in autonomous vehicles. For the sake of simplicity, we will focus on level 4/5 autonomous electric cars.

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Impact of vehicle autonomy on electric drive range

Fully autonomous cars (level 5) will have many more electronics (sensors, sensor fusion box, ECUs for drive-by-wire systems), than standard drive vehicles. With a fully electric powertrain, these electronics that enable autonomous functionality will need to be powered by the high-voltage battery, through a DC-DC converter for the 12-V line. This increased burden will reduce electric drive range and thus pose a critical challenge for developers of autonomous electric vehicles. On the other hand, machine driving is expected to deliver a smoother drive pattern compared to human driving behavior. Smoother drive cycles allow more efficient use of battery energy, delivering a higher electric drive range. These trade-offs become a lot more interesting if we quantify the end effect!

The first part of the design we can look at is how the overall power requirements of the significant number of sensors and the sensor fusion box effect the total power consumption and in turn the overall drive range. To quantify the potential effects of different levels of autonomy as well as the potential for future improvements to the different components, it makes sense to look at several levels of total power requirements for the autonomous functionality enabling electronics systems. Figure 1 shows the reduction in drive range with different levels of power (and associated thermal) consumption from the autonomous systems as analyzed with Simcenter system simulation software. For this example, we are considering a compact sedan with a pure electric powertrain. The challenge associated with minimizing power consumption becomes clear when looking at the reduction for power levels of 2-4kW which is the range of many of the current test vehicles on the roads today. This analysis further shows the advantage of using a low power-consuming centralized sensor fusion architecture, such as Mentor's DRS360™ that promises to limit sensor fusion box power consumption to 100W.

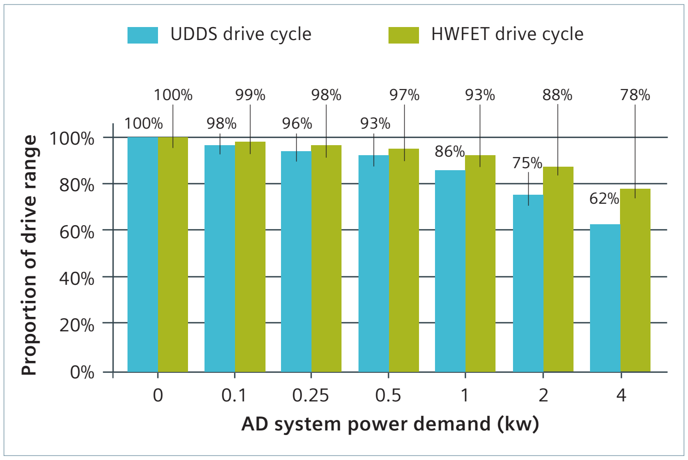

Figure 1: Impact of autonomous driving (AD) system power demand on electric drive range, simulated with Simcenter system simulation software.

However, autonomous driving can also have a potential benefit to drive range. Let us consider the example of a level-5 autonomous, electric, compact sedan with 30 sensors (lidars, radars and cameras), and one sensor fusion box. The total load for this example is 1kW. How the drive profile will change for a connected

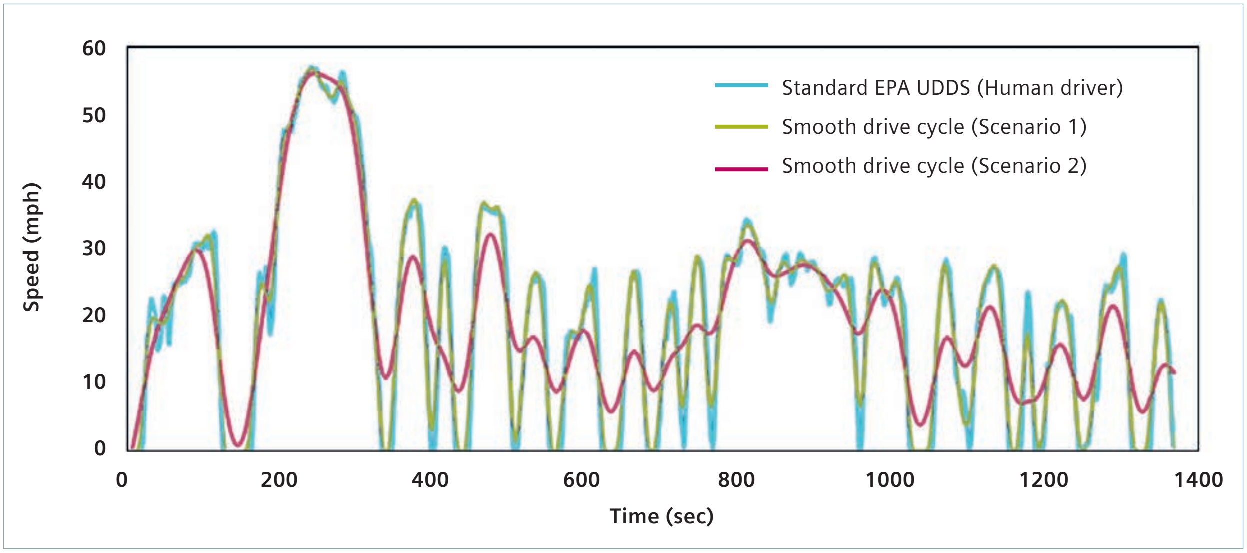

Figure 2: Representative changes in driving behavior as driving is shifted from humans to machine.

autonomous vehicle is unknown and is an area of active research. Auto OEMs with autonomous vehicle test fleet on the road may have information about drive cycle smoothing for their vehicles. Alternatively, as auto OEMs are increasingly relying on virtual traffic scenarios and vehicle driving simulations for autonomous vehicle testing, simulation tools such as Simcenter Prescan™ and its connection with DRS360™ can be used to determine what level of drive profile smoothing to expect from machine driving.

For this example, we will use two scenarios from the simulated drive-cycle smoothing scenarios discussed in the research[2] conducted by Dr. Kockelman's group at the University of Texas in Austin. Scenario 1 (Figure 2) represents moderate smoothing of the drive profile throughout the cycle but especially at the points of complete stop and acceleration. Scenario 2 represents significantly more smoothing to a point where the connected autonomous vehicle can anticipate upcoming stops during city drive and slow down/accelerate accordingly without coming to a complete stop. For both these scenarios, the overall commute time has no change.

For city driving at 25°C ambient conditions and for this specific vehicle study, our analysis showed (Figure 3) that the added electronics power demand on the main battery resulted in a nearly 16 percent reduced drive range. Reduction in drive range will be far higher if a higher power consuming, sensor-fusion box is used.

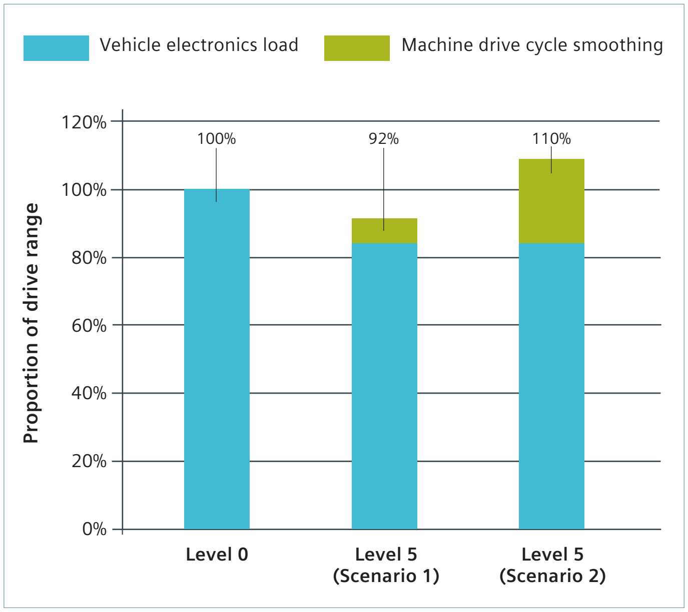

Figure 3: Energy and thermal management simulation, using Simcenter Flomaster, for level 4/5 autonomous electric compact sedan accounting for increase in vehicle electronics and potential drive cycle smoothing that will come with machine driving. Simulations are for city drive cycle at 25°C ambient conditions. Drive cycle smoothing scenarios are provided by Dr. Kara Kockelman of UT Austin.

Scenario 1 offers an 8 percent increase in electric drive range by better allocating battery energy to the wheels but still results in 92 percent electric drive range for a level 4/5 autonomous EV compared to a level 0 car. The significant increase in smoothing in scenario 2 delivers 110 percent electric range for a level 4/5 autonomous vehicle compared to a level 0 electric vehicle.

This analysis shows that the overall electronics load, especially power (and thermal load) of the sensor fusion box (which likely is the biggest power draw component from an autonomous driving system), needs to be minimized. More importantly, depending on the change in the driving profile and what manufacturers are able to achieve through their machine-learning algorithms, the overall electric powertrain energy efficiency (for example, the battery design) needs to be improved or the battery pack size resized – either can help reduce cost. These numbers will differ depending on the characteristics of the powertrain (battery and motor design), vehicle size, electronics integration, and EE configuration of the vehicle, among other factors. But the underlying opportunity for e-powertrain optimization, outlined here, remains valid.

Other factors, such as platooning, especially for trucks/ commercial fleet highway driving, can further enhance drive range, as shown in the work from NREL[3] showing the effect on fuel consumption of platooning a class-8 vehicle. This can open up additional opportunities for resizing the battery and other powertrain components.

Electric powertrain life and reliability implications

One major application for level 4/5 autonomous electric cars is the ride-sharing fleet, and it is expected that these vehicles may log 80,000 miles or more per year. For reference, New York taxis log approximately 70,000 miles per year. This is a sharp contrast to today's predominant driving pattern where cars are parked more than 80 percent of the time. For batteries in electric vehicles today, shelf life (a measure of battery aging when it is resting at a certain state of charge and temperature), plays a significant role, in addition to their cycle life (a measure of battery aging when it is charged and discharged continuously) in determining overall battery life. For ride-sharing, autonomous electric vehicles, emphasis will be significantly more on cycle life while designing and characterize batteries. Impact of new usage profile on battery life, design improvements for battery chemistry, pack and vehicle integration specifically for autonomous EVs can be easily undertaken with Siemens battery simulation portfolio. Similarly, a smoother driving profile with machine driving can significantly reduce overall thermal load for the battery, inverter and motor, which will provide opportunities to innovate new thermal management schemes for e-powertrain components. For instance, Figure 4 shows the change in heat generation for electric powertrain components that may come with drive cycle smoothing with machine driving. For the drive cycle smoothing cases shown in Figure 2, inverter sees ~25 percent and ~40 percent reduction in overall heat generation with drive cycle smoothing scenario 1 and 2, respectively. Since temperature is the leading indicator of an inverter's reliability, the reduction in thermal load results in lower stringent thermal management requirements to ensure field reliability. Simcenter integrated testing and simulation workflow for inverter thermal management and lifetime characterization[4] can allow engineers to evaluate new architectures and accurately estimate inverter life for autonomous electric vehicles. Analysis showed similar reduction in overall heat generation for battery. drive cycling smoothing impacted motor overall heat generation strongly- ~30 percent with smoothing scenario 1 and ~60 percent with scenario 2, since the acceleration demand went down drastically. Potentially less demand for thermal management offers new opportunities to minimize overall volume for motor without sacrificing its performance or life, leveraging Simcenter Motorsolve™. These factors can allow OEMs to further reduce e-powertrain cost.

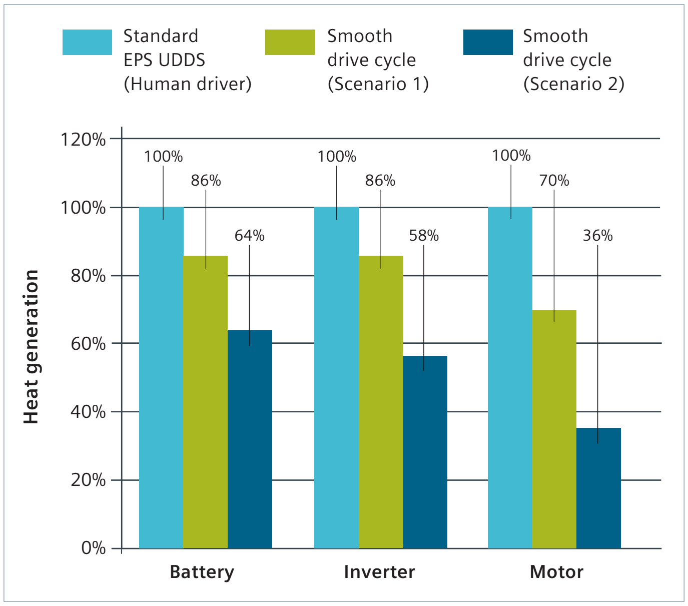

Figure 4: Comparison of heat generation for battery, inverter and motor for different levels of machine driving profiles.

Conclusion

In summary, adding level 4/5 autonomous functionality to the electric powertrain introduces new challenges and opportunities that warrant resizing/optimization of the battery, motor, and inverter, as well as their interactions in a powertrain. The example analysis shown here is helpful for manufacturers to not only account for powertrain design needs, but also to set power consumption targets for sensor fusion and other electronics vendors as well as develop target drive-cycle smoothing that needs to be achieved via machine learning and vehicle control strategies. Our combined Mentor-Siemens portfolio is unique in that it allows auto OEMs to frontload these considerations from earliest design stages, and create an accurate digital twin of an autonomous electric vehicle and a digital twin of autonomous vehicle driving behavior.

So the bottom line: adding electric powertrain and autonomous vehicle makes perfect sense but like any other partnership, this one also needs work.

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