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The new Opel-Ampera-e.
Battery, Propulsion System and their operation.

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Executive Summary

The Opel Ampera-e Electric Vehicle is setting milestones in Range, performance and fun to drive electric. Based on the experience of the Chevrolet Spark EV battery electric vehicle and the Opel Ampera this is the result of a new drive system and continuous development of the Battery system.

Insights and technical highlights in key technologies of the Ampera-e propulsion system and its battery will be illustrated.

Figure 1: Opel Ampera-e: Integrated Propulsion System

First results from data-acquisition-systems in field-operated vehicles and initial customer behavior in real life experience will conclude the presentation.

1 Progress in Propulsion system Components

Opel has launched the new Ampera-e Electric Vehicle early 2017. The propulsion systems for this car as well as for the Chevrolet Bolt EV [2] were developed with the experience from the Chevrolet Spark EV battery electric vehicle, but for increased vehicle capability. It now propels a new, larger electric vehicle with significantly greater electric driving range. Through extensive analysis, the primary propulsion system components, which include the drive unit, traction electric motor, power electronics, energy storage and on-board charging module, were optimized individually as an integrated system. The new design and numerous optimization loops delivered improvements in propulsion system energy, power, torque and efficiency. The results deliver outstanding EV range and fun-to-drive acceleration performance.
This paper describes the new propulsion system, starting from its requirement definition all the way down to subsystems design and performance, including remarkable optimization details, resulting from rigorous analysis. The paper compares the performance characteristics with vehicle and subsystem level figures of GM’s Chevrolet Spark EV [5,6[] which was previously introduced in US, Canada and Korea back in 2014.

The new Ampera-e virtually eliminates “range-anxiety” through greatly improved range and great charging options, while it further improves drive performance characteristics in comparison to the Chevrolet Spark. The improved propulsion system and range will make this car eligible for purchase by a much wider audience of customers and thus will substantially contribute to the rising share of Battery Electric Vehicles (BEV) under the passenger cars.

1.1 Propulsion System Components

Overview of the Ampera-e Propulsion System Components:

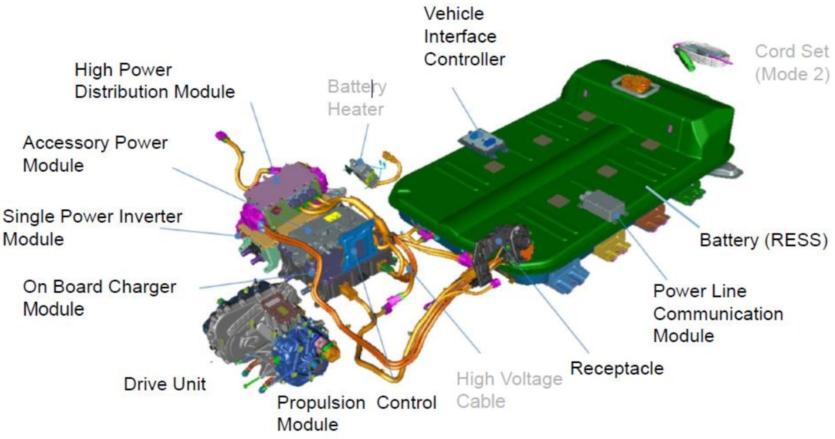

Figure 2: Ampera-e Propulsion System Components

1.1.1 Traction Battery

Starting from the energy storage system the key components for the Ampera-e propulsion system is the rechargeable energy storage system (RESS), commonly known as the battery pack. It provides a high voltage (HV) source of propulsion power and energy. The battery pack had to balance the need for high energy, power, and efficiency in a compact, lightweight package.

Key improvements enabled the high energy density of the mass produced Battery Pack:

1. Packaging/Space Utilization Optimization: Goal of the RESS internal design was to maximize usage of its internal space without compromising the integrity and robustness of the overall system. Components (e.g. RESS heater, etc.) which are normally integrated into the battery pack were packaged to the under hood location to maximize the amount of space for battery cells. The pack has five sections in total.

2. Cell and Electrode Format Optimization: In total, there are 288 cells in the pack. The pack consists of 5 sections and each section has two modules. The amount of cells are evenly distributed within each of two modules. There are 96 cell groups in total and 3 cells per group in parallel (3P). The optimization of the module, cell, electrode and count ensured that the required amount of power and energy could be achieved simultaneously, while meeting the voltage and current specification of the inverter.

3. Chemistry Selection: The ideal choice is a Nickel-rich Lithium-ion based chemistry, which provides thermal resistance, is environmentally friendly, enables high charge rate and delivers a long life within automotive requirements. The nickel-rich Li-ion chemistry provides improved thermal performance over other chemistries, allowing the use of a smaller active cooling system for more efficient packaging.
4. Active Cooling and Heating Optimization: The pack's temperature directly influences its performance and life expectancy. An active thermal liquid cooled system, similar to the Chevrolet Volt [5], was placed for circulating coolant through each module and each section of the pack. A cooling fin is built in between cells and each fin is connected to the cooling plate.

5. Safety and Crash Regulation Requirement with optimized topology: Safety was the overriding priority. All design concepts were carefully evaluated to ensure that Motor Vehicle Safety Standard regulations as well as internal crash design requirements were met.

1.1.2 Drive Unit

The Drive Unit (DU) of the Ampera-e EV was designed to optimize package space, noise, mass, manufacturability, application flexibility, cost and efficiency. It provides several functions including electric motor traction, motor end cover, motor cooling, lubrication system, sumps for cooling and lubrication, gear reduction, differential split to outputs, park system, electric mode switch (PRNDL), 12V pump, filter and accessory support in a maintenance-free design. Figure 4 shows a labeled cross section showing the major DU components and outlines how all the internal and external components are integrated.

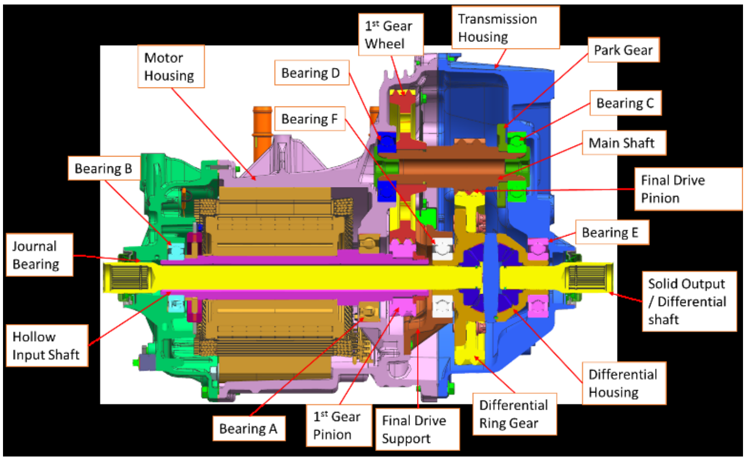

Figure 3: Sectional view of Ampera-e Drive Unit

1.1.3 Electric Motor

A permanent magnet (PM) motor is used in the propulsion system of the Opel Ampera-e for its inherent properties of higher efficiency and higher torque/power densities [9]. The rotor was an interior permanent magnet (IPM) type where the magnets are buried inside the rotor. The IPM motor has well-known properties such as i) extended constant power range, ii) good overall efficiency, iii) good power factor etc., which make this motor a favorable candidate for automotive propulsion application.

Rotor Design

High energy Neodymium Iron Boron (NdFeB) type magnets were used in the rotor design. The magnets were buried inside the rotor in a two layer 'V' arrangement (figure 8). A double-layer arrangement of magnets offers design-flexibility that allows to lower motor noise. Additionally, double layer arrangement enhances rotor saliency that results in improved motor performance, especially motor power at higher speeds.

The rotor and stator designs have implemented several key design features to mitigate noise and vibration. In the rotor, the angular placement of magnets was varied asymmetrically between adjacent rotor poles. This variation is very subtle and is not very noticeable in the rotor geometry of figure 8, however, strongly influences motor torque ripple and radial force. Torque ripple and radial force are the two major drivers for drive system noise and vibration. This design feature minimized motor noise while almost not affecting motor performance. Additionally two small rotor slots were stamped in the rotor lamination near the rotor outer periphery. The placement of the rotor slots are varied asymmetrically between adjacent rotor poles. This variation also influences torque ripple and radial force and further lowered motor noise.

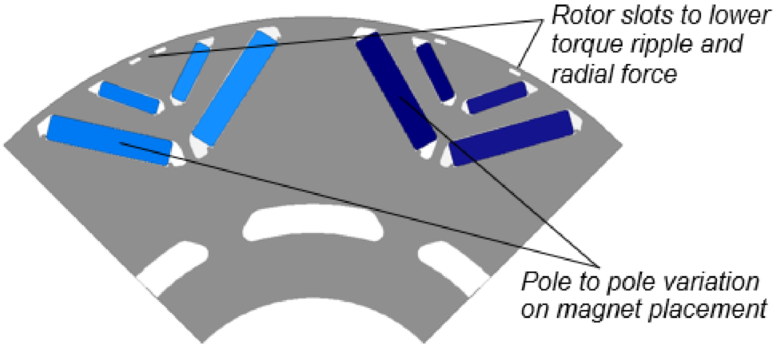

Figure 4: Rotor section of Ampera-e Motor

Stator Design
A bar-wound or hair-pin (Figure 5) stator was designed for the Ampera-e electric motor. The stator is shown below in Figure 6.

A bar wound stator construction has known benefits such as: i) higher slot fill, ii) improved thermal performance, iii) shorter end-turn lengths, iv) fully automated manufacturing process, compared to a more conventional stranded stator design. However, bar wound constructions suffers from winding AC effects that increase motor joule losses at higher motor speeds. In order to lower the winding AC effects and joule losses at higher speeds, the Ampera-e stator used a six-conductor per slot design in contrast to the four-conductor per slot design implemented in Chevrolet Spark EV motor.

Figure 5: Hair-pin Design Winding

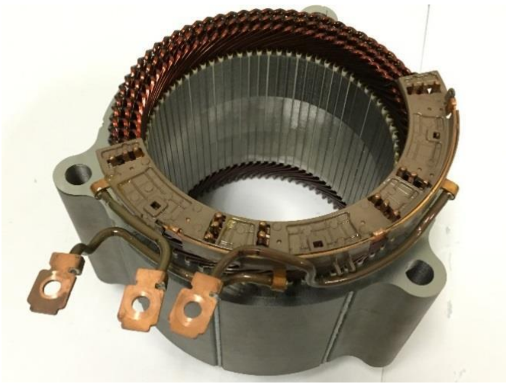

Figure 6: The Ampera-e Motor Stator

1.2 Operation experience of the new Ampera-e

As the Ampera-e sets milestones in performance like range a first evaluation of customer behavior from an Opel –internal fleet is evaluated for Vehicle- and Battery operation as well as customer charge behavior. Ten vehicles operated by Opel-employees in the first half year 2017 were evaluated for more than 100000km.

1.2.1 One Pedal Drive

One Pedal drive with its potential for high regeneration down to full stop provides a new experience of driving. A real world driving example demonstrates system reaction on drivers commands.

1.2.2 Battery usage

According the relatively low distance between two charge events the battery is mainly operated above 50% SoC. DC Fast Charge (> 20kW) happens in about 10% of the cases.

1.2.3 Charge behavior

Even if the vehicle is capable for ranges up to around 400km with one charge in daily use (WLTP) this is by far not reached in normal operation which usually takes place below 150km between charge events. Long distance rides and high charge energy SoC currently restricts to engineering tests and some enthusiastic drivers.

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Authors

Manfred Herrmann, born 1961, received his degree in Electrical Engineering from the University Erlangen-Nuremberg. From 1992 to 1997 he developed electric vehicles at Adam Opel AG with various battery systems. With the electrified Astra “Impuls3” he oversaw the Rügen field test for electric vehicles. Later he developed GM’s first fuel cell vehicles, lead the project “Hydrogen3” and set-up the vehicle fleet Hydrogen4.

In 2007 Mr. Herrmann was part of the team to define the battery system for Chevrolet Volt and Opel Ampera. Later on he has managed the technology for future battery systems and electric propulsion technology for Opel. Since 2015 Mr. Hermann is responsible of the electric propulsion system topics, from electric grid to torque, of the Ampera-e at Opel Vauxhall.

Manfred Herrmann is Opel’s representative for battery topics in the NPE (German National Platform EMobility). He is member of the E-Motive board and chairman of the “Forschungsvereinigung Antriebstechnik” - working group on electrical energy storage systems (FVA, German association for research on propulsion technology).