Drivers of Electromobility

Flame Retardancy, Heat and Tracking Resistance of Electric Vehicles

The transformation from the combustion to the electric engine entails several imponderabilities for the plastics industry. In part, electric drives have completely different material requirements which are becoming specifically evident with the increasing use of appropriate vehicles. The following article presents an overview of the most important changes.

In electric vehicles, the change in engine technology also entails new requirements for the plastic materials used (© Adobe Stock, Aliaksandr Marko)

With the move towards electromobility, the automotive industry is facing a radical change. In the transition period, manufacturers will strongly diversify the powertrain. By optimizing internal combustion engines (ICEs), switching to alternative fuels and introducing hybrid cars, they are reducing their overall fleet emissions. At the same time, they are building competences in electric engines expand their offers of fully electric vehicles (EVs). The fuel cell vehicles developed by some manufacturers are also driven by electric engines.

Electrification requires various new systems and components. This is the case regardless of whether the electric engine is powered by electricity from a large battery module by a fuel cell in conjunction with a smaller battery. Some of these additional components include high-voltage chargers, lithium-ion batteries, fuel cells, powerful electric engines, inverters for direct-to-alternating (DC-AC) transformation and DC-DC converters (**Fig. 1**).

The electric powertrain (**see Box p. 13**) typically operates at high voltage with currents of several hundred amperes (A). Therefore, the safety and reliability of the drive system have become more essential than ever. Engineering plastics used for electrical insulation or structural housing components will see sharp increases in requirements for thermal aging resistance, flame retardancy and insulation properties. Flame retardants as well as dielectric strength and comparative tracking index (CTI) are clearly gaining in importance. Ignoring these requirements would result in significant safety risks and considerable reduce the reliability of vehicles. For these reasons, material suppliers are collaborating with tiers and OEMs to develop materials that will meet the requirements and boost the performance of EVs.

Flame retardants for use in plastics are a good example of the change in requirements. In the automotive environment as such they are not desirable, as they mechanic properties and the flowability of materials, while also resulting in higher weight and cost. However, the need for flame retardancy is expected to greatly increase with all the components in high-voltage (HV) powertrains, from the charging plug to the electric engine. On the one hand, this is due to proactive initiatives taken by OEMs or tiers. On the other hand, it can be assumed that supervisory authorities will also impose stricter regulations.

Flame Protection Is Required

Flame protection in transportation is all about increasing the escape time in case of an emergency. Hence, it is no surprise that in airplanes, where escape is complicated, even seats and carpets need to pass very high flame retardancy specifications. Clearly, passengers can escape much readily from a car. Currently, passing the required flame tests is therefore rather easy for cars. At present, there are only limited applications and manufacturers that require the use of V0 certified plastics according to UL standard 94 in vehicle on-board electrical insulations.

However, the situation is very likely to change fundamentally with the transition to high-voltage electrification and unattended battery charging. High currents and high charging loads increase the fire hazard. Moreover, the HV system is associated with general risks such as potential short circuits or sparks. There have already been multiple reports of serious fires caused by on-board lithium-ion batteries even in parked and switched-off cars. EVs without dedicated flame protection are a safety risk. Higher requirements must therefore be expected in terms of flame retardancy (UL94 V0) and glow wire ignition temperature (GWIT).

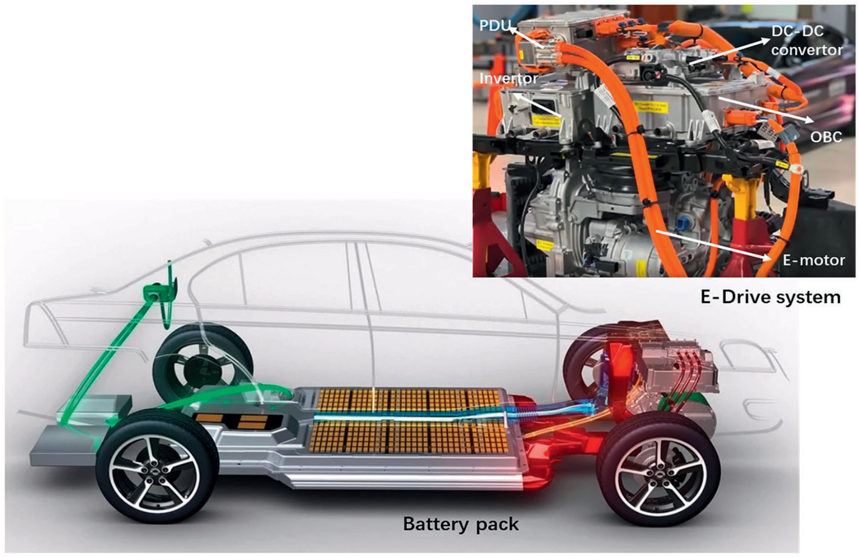

Fig. 1. Key components of the high voltage drive train system of a Chevrolet Bolt (© DSM)

In addition, lightweighting continues to be of great importance for automotive designers, albeit for fundamentally different considerations with regard to the different drive systems. In vehicles with combustion engines, every gram of weight reduction directly contributes to lower emissions, hence lower potential penalties as per the latest CO_2 targets in the EU. For battery electric drives, designers need to compensate the extra weight of the high-capacity batteries, which can quickly add up to around 800 kg for a car with a good range. More and improved lightweighting structures are also needed for preventing a driving experience compromised by the inertia of a heavyweight »

Fig. 2. PA is a very suitable material also for EV applications. For instance, PA6 and PA66 are used in HV connectors, HV PA 4T busbars and contactors (© DSM)

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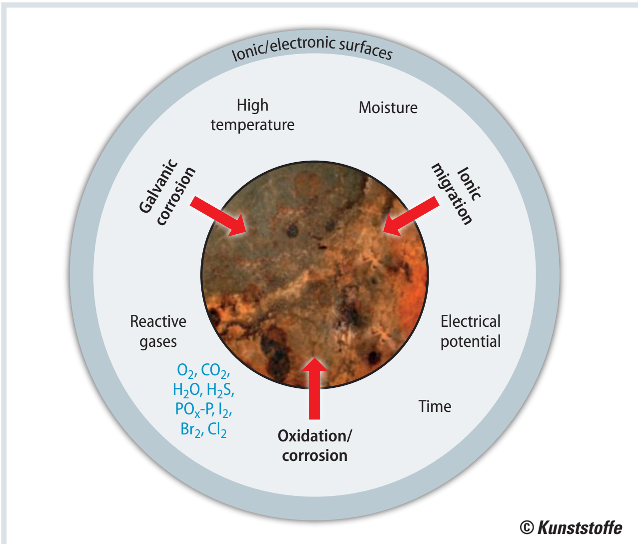
source: DSM

Fig. 3. Terminal corrosion caused by outgassed heat stabilizers or migration of other ionic impurities in the plastic (source: DSM)



vehicle. This will increase the use of plastics in applications hitherto dominated by metals, such as for parts requiring enhanced stiffness at high temperatures between 150 °C and 180 °C or for housings of electronic control devices. In order to meet the requirements of electromobility, materials supplier DSM, Heerlen, The Netherlands, has developed several engineering plastics targeted specifically at HV systems of hybrid and fully electric vehicles (**Fig. 2**). These include aliphatic polyamide (PA) 6, 46, 66, 666 and 410, aromatic PA 4T (polyphthalamide, PPA), PPS, PBT, PET and thermoplastic copolyether ester (TCP) grades. Among all these polymers, PA6, PA66, PA 4T, PBT and PPS are very well suited to the needs of the electric powertrain.

Quite often, halides such as copper-iodide (CuI) based heat stabilizers are used polymers to achieve good thermal resistance. This keeps the mechanical properties of the structural or insulating plastic on a high level even at long term exposure to elevated temperatures. Heat and humidity, however, can cause some hydrolysis in the plastic, during which iodide (I_2) is released, which in turn can lead to electrical corrosion of metal contacts or pins. This will not only affect metal parts in direct contact with the heat stabilized plastic, but also others located only in physical proximity to the plastic, e.g. enclosures with critical electronic components inside (**Fig. 3**).

Given the ionic nature of I_2, a constant bias voltage will accelerate the migration of these ions and thus accelerate the effect of electrical corrosion significantly. This can reduce the conductivity of components, such as busbars, leading to increased heat generation up to component failure. Moreover, it can also change the current/voltage characteristics and subsequently the switching profile of components such as integrated circuits (ICs) or transistors.

As a long-standing material supplier to the electronics and automotive industry, DSM has developed various different engineering plastics custom-tailored to critical electrical applications (**Table 1**). Free of metals and inorganic heat stabilizers such as CuI, these materials ensure high reliability for sensitive automotive components such as sensors, connectors, ADAS or electronic enclosures. Furthermore, in close cooperation with Stuttgart, Germany, based automotive supplier Bosch, DSM has developed a dedicated test facility for measuring the impact of electrical corrosion for different application cases both with and without direct metal contact.

To further minimize the problem of electrical corrosion caused by additives, DSM has introduced ForTii Ace as a high

	Akulon 6	Akulon 6.6	Arnite T	Arnite A	Stanyl	Ecopaxx	Xytron	ForTii
UL94-V0, halogen-free	XG-FKGS6 K225-KS	SG-FKGS6			HFX portfolio		G3080R G4080R	F11 TX1 T11 E11
UL94-V0, halogen containing	K-FKGS6/B		TV4 261 SF TV3 260 SXF		TE 250F6 TE 250F3 TE 250F8 TE 351 46HF5040/50			
UL94-HB	K224 G3-G7 K-FKG3 K-FKG6 K-FKG8	S223-KG5	TV 230 TV 240 TV 260 TV 261 TV 261/G TZ6 280 TV4 260 HS HR T08 200	AV2 370 XL AV2 370/B	TE 200F6 TE 200F8 TE 341	Q-KG5 Q-KG6 Q-KS		KX12 K11 JTX2 JTX8

Table 1. DSM portfolio of compounds without critical halide salts or red phosphorous, which could lead to electro corrosion (source: DSM)

temperature PPA with the highest Tg (glass transition temperature) of 160 °C amongst all polyamides. In applications requiring a continuous use temperature up to 150 °C and above, the high Tg eliminates the need for heat stabilizers in the compound without impairing the mechanical properties of the polyamide.

ID.3 Reaches USD 100 per kWh

The efforts of automotive manufacturers to increase the driving range of EVs are also affecting the plastics used. So far, the acceptance and sales of EVs are still rather low, above all due to high purchase prices, an insufficient charging infrastructure and the aforementioned, unsatisfactory range. EVs will reach cost parity with combustion engine cars only if battery pack costs drop to USD 100 per kWh. We can expect that growing volume demand and advances in battery performance will keep the costs shrinking. Advances in this direction were confirmed last year by Volkswagen AG during the IAA International Motor Show in Frankfurt, Germany. Along with the launch of their new ID.3 EV, the company also announced that given their huge battery deal with Asian suppliers, they have reached a cost level of USD 100. However, it remained unclear if this referred to the cost of the complete battery module or only the cells. At the same time, with increased governmental focus on reducing municipal fine dust pollution, we can also expect the charging infrastructure to be expanded.

One of the key focal points for automotive designers, therefore, is to increase the range of EVs. This can be done in four different ways:

- By raising the battery capacity through either more cells or by newer battery technologies,
- by using higher-efficiency DC-AC inverters and DC-DC converters,
- by using higher-efficiency AC motors with further reduced component count,
- by boosting the battery power through higher DC voltages.

Mild hybrid cars have a 48 V low power battery. They cannot drive fully electrically, as their electric motor only assists the combustions engine. In contrast, most fully hybrid cars and commercially available battery electric vehicles run at voltages between 200 V and 400 V, with a trend towards further increasing the battery voltage up to 800 V. Likewise, the charging infrastructure in Europe is also being expanded to accommodate such high voltages. Ionity GmbH, Munich, Germany, a joint venture of BMW, Daimler, Ford, VW, Audi and Porsche, is currently developing a pan-European network of ultra-fast high-voltage chargers (for up to 800 V), with the new Porsche Taycan being one of the first vehicles in the market to utilize this HV technology.

In addition, various industry players are actively working to move to even higher voltages in the range of 1000 V and above. A high-voltage charging system of 1000 V can reduce the battery charging time for a range of 1600 km to about 1 hour, which means the driver can fill up power for 400 km in just 15 minutes. Such charging times are considered acceptable for consumers and a big relief when traveling longer distances.

To achieve an overall higher electrical power at minimized power losses, the increase of voltage is preferred as opposed to increasing the current, since electric losses in conduction (P) scale with the square of current (I^2) (**Fig. 4**). Therefore, the electric powertrain requires high-voltage components and systems capable of delivering sufficient power to drive the electric engine while also minimizing the battery charging time. With high voltages, engineers need to take extra care in the design of parameters such as dielectric strength, creep distance and tracking resistance.

A key requirement for increasing the safety and reliability of the electrical systems is to avoid tracking between contact pins. Such tracking can occur if the surface of an insulation material gets carbonized and hence increasingly conductive. The root cause for such carbonization is surface contamination through ions, which are included in moisture, dust or other particles that get deposited over time on the plastic surface between two contact pins.

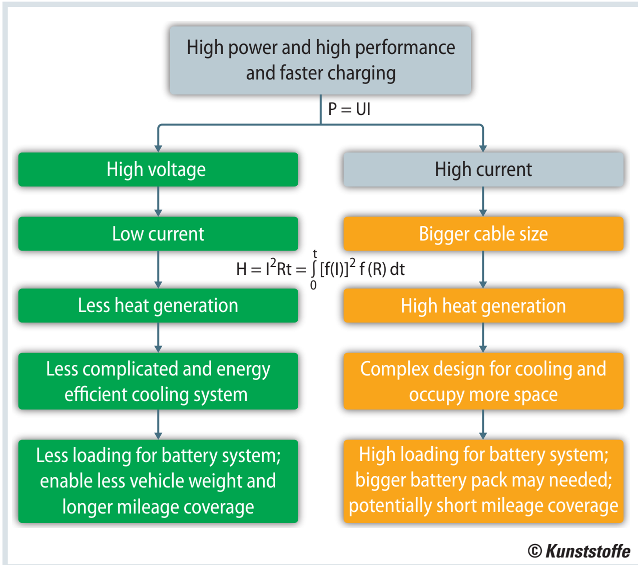


Fig. 4. In order to increase the battery performance, it is usually more advisable to increase the voltage rather than the current (source: DSM)

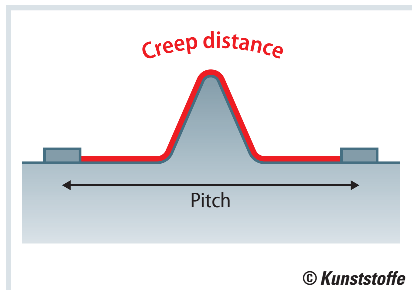


Fig. 5. The creep distance is often deliberately increased to prevent the flow of current between two contacts (source: DSM)

In principle, designers have three options to prevent this from happening:

- Increase the creep distance between the two contact pins (the actual surface distance of the plastic) by introducing a rib or recess.
- Avoid contamination of the plastic insulator surface from particles or moisture by encapsulating the entire system.
- Use an insulation plastic with an intrinsically higher CTI.

Creep distance is the actual surface distance between the contacts (**Fig. 5**). If the direct distance or pitch between the contacts remains the same, the creep distance must be increased to avoid tracking between »

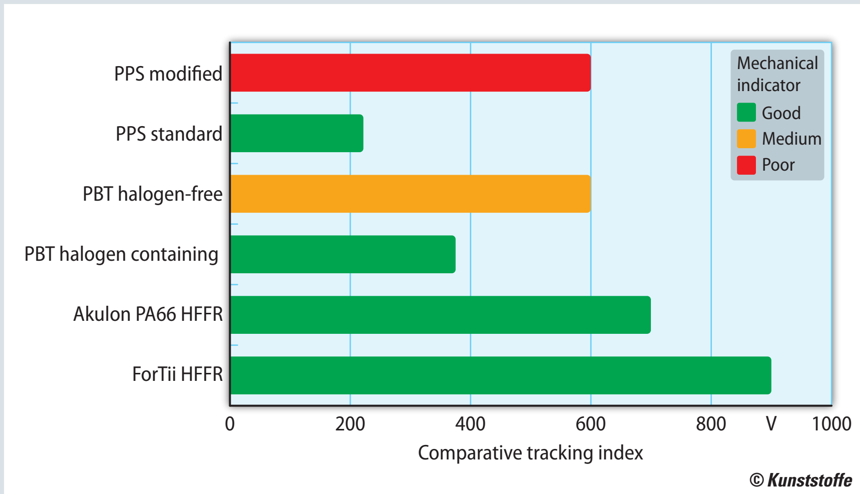


Fig. 6. Comparison of different polymer classes by tracking resistance. Colors indicate respective mechanical strength (source: DSM)

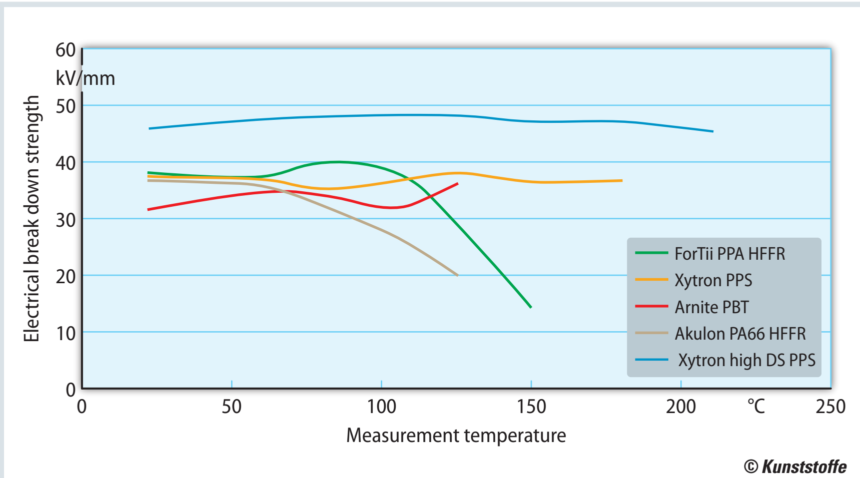


Fig. 7. Electric breakdown strength before aging at elevated temperatures. Most polymers show a decline in breakdown strength at rising temperatures (source: DSM)

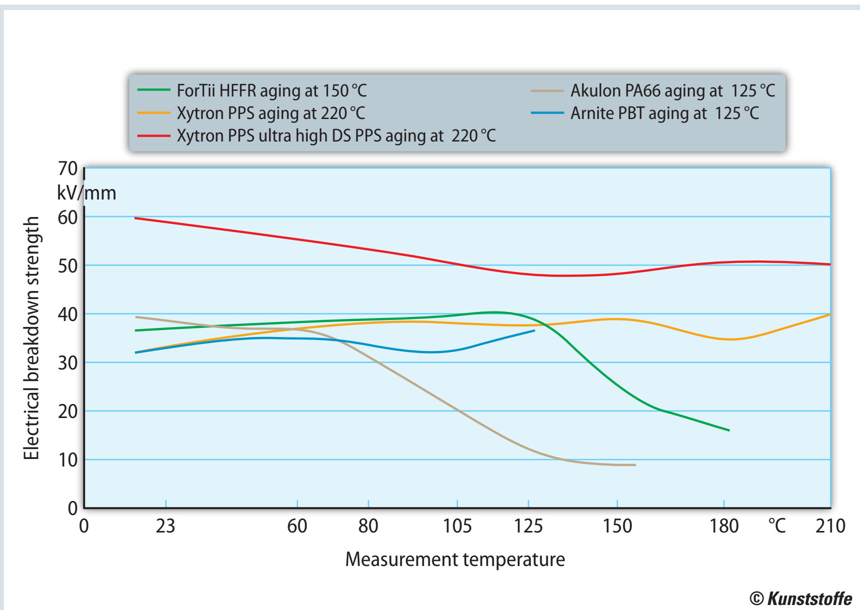


Fig. 8. Electric breakdown strength after aging at elevated temperatures. The curves of the materials are similar before and after aging. As a result of aging, the dielectric strength decreases as expected (source: DSM)

these pins at higher voltage. When designers are forced to squeeze additional electronic functionality such as glycol cooling into the often confined available space, it will hardly be possible to increase the creep distance, especially not without increasing the pitch between the contact pins. Encapsulating such connectors and plugs to avoid external contamination is not always feasible, either. In such cases, the designer can use insulating plastics with a higher CTI value (**Fig. 6**). In this way, the risk of tracking can significantly be reduced.

Without Halogens, Phosphor and Halides

DSM offers halogen-free flame retardant plastics that deliver the required electrical performance, and is the first and only company worldwide that has globally launched compounds for high-voltage applications with a certified CTI rating of >700 V (for Akulon PA66) and >850 V (for ForTii PPA). These compounds are free of metals, halogens, red phosphorous and halide-based heat stabilizers, so that potential electrical corrosion of any metal used in the assembly of the components can be avoided. They are also available in orange colored grades.

To ensure highest safety and reliability – not only during technically critical application testing on component level, but also during the entire lifetime specified by OEMs – DSM has carefully studied the insulating properties of plastics at room temperature as wesll as after long-term aging at high temperature. The data provides a good reference to engineers on the actual lifetime performance of the electric powertrain at actual working temperatures.

Reasons for Electric Breakdown

Fundamentally, there are three electric breakdown mechanisms for a plastic resin as an insulation material:

Intrinsic or material-specific breakdown, which depends on the presence of free electrons capable of migration. When an electric field is applied, these electrons are accelerated and tend to escape from the trap of the molecular structure. When the field strength reaches a certain limit, they are then released from the molecules. Accelerated by the electric field, the electrons collide with each other, which eventually leads to an avalanche effect resulting in electric breakdown.

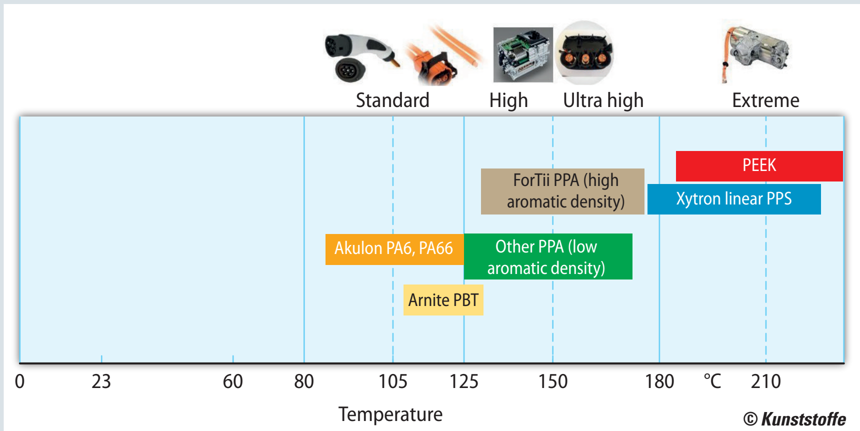


Fig. 9. DSM high-voltage material portfolio for high operating temperatures. Different materials are recommended depending on the temperature range (source: DSM)

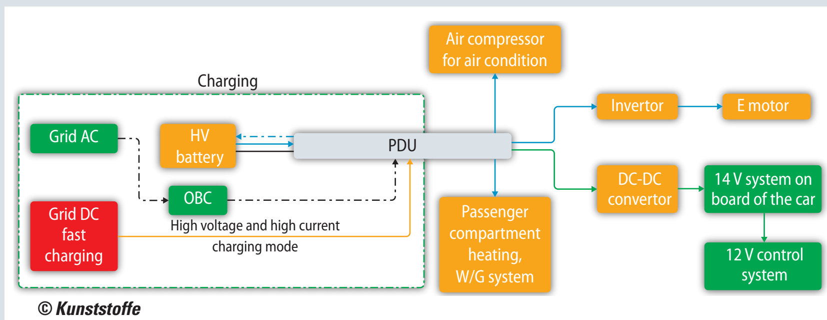
Thermal breakdown, which depends on the Tg of the plastic compound and on the polarity of the molecular structure, and it is the main failure mechanism for a plastic compound. When the temperature rises above Tg, this has two effects: First, the molecules of the polymer start to become movable, which makes them "rub" each other and creates energy loss (dielectric loss). As a consequence, the temperature of the resin will increase further. Second, the volumetric resistance of the polymer will decrease. This weakens the molecular trapping of electrons, which will tend to cross the from the valence into the conduction band. In a high-voltage field, this will result in a higher amount of current passing through the polymer, which can increase the temperature of the polymer dramatically. **Figure 7** shows the correlation of the electric breakdown strength decrement vs. the temperature increment of plastic compounds before aging. Characteristically, the dielectric strength of many polymers decreases at higher temperatures.

Discharging breakdown, which can occur when there is a flaw in a plastic part, caused by voids, contamination or impurity. Normally, these flaws are consistent or show a medium or lower dielectric strength. In a high-voltage field, such an inhomogeneous structure will lead partial discharge, which can result in breakdown. **Figure 8** illustrates the electric breakdown strength of different polymers after heat aging.

Electrical properties, such as CTI, electric breakdown and volumetric resistance are important parameters when selecting the right insulation material for high-voltage components. **Figure 9** provides an overview of potential material choices for electrical applications within the powertrain. For materials used in the high voltage path DSM recommends a lower limit of 10 kV/mm of electric breakdown strength with a related volumetric resistance of $10^8\,\Omega$cm at the respective operative temperature of the application.

Due to their high Tg and aromatic content, halogen-free ForTii PPA compounds offer a sufficient electrical safety margin even at elevated continuous use temperatures of 160 °C. Xytron PPS, because of its linear and symmetrical molecular structure in combination with high aromatic density, shows much lower polarity than most other polymers. This makes it an ideal material for components designed to work in the harshest conditions and stand up to peak operating temperatures over 200 °C. For these reasons it is often utilized in environments where applications can be exposed to severe chemical, oil or other aggressive agents. ■

Electric Powertrain



Functional diagram of the powertrain in a battery electric vehicle. Electrification adds further components (source: DSM)

A standard electric powertrain system consists of a power distribution unit (PDU), an on-board charger (OBC), an inverter, a converter and an e-motor.

Inverter: Sometimes also referred to as an intelligent power control module, the inverter transforms the direct current (DC) supplied from the battery to three-phase alternating current (AC) to drive the e-motor. Components found inside the inverter can include insulated gate bipolar transistors (IGBT), thick metal busbars to carry high currents, three-phase terminal blocks, capacitors and inductors.

PDU: The power distribution unit centrally distributes power to various units, working as a dispatch station in the EV system. Busbars and contactors are typical key components inside the PDU.

Convertor: The converter changes the voltage from the higher battery levels of in between 400V and 800 V to the lower 12 V required by other power consuming units, such as the infotainment system in the car, without changing its DC character. Field effect transistors, capacitors, inductors and busbars are typical components assembled in the converter.

OBC: An on-board charging device is the interface between an external charging plug and the PDU. In contrast to the inverter, it transforms AC to DC voltage. It works under the slower charging mode and is required if charging is done on the AC net, such as at common domestic wall plugs. Given the typically much lower power range of the grid between 3.3 kW and 7.9 kW, charging is slower compared to the high-voltage DC fast chargers.