Charging by Pantograph

Short Charging Break for Electric Commercial Vehicles

Unlike passenger cars, electrically powered commercial vehicles have special power requirements: As fixed assets they contribute to generating sales over the long term. So, they should be operated with as little downtime as possible. This means that charging times must be kept brief, which requires a high charging power. Charging systems with plug connectors are now reaching their limits, since the amount of power they can transmit is limited by wire gage and weight. Pantographs can provide relief. With charging powers of up to 1 megawatt, the technology promises high vehicle availability. But exactly what are pantographs, and how do they work?

Pantographs are sets of scissor-like contact arms that draw their power for vehicle operation from stationary masts. The commercial vehicle industry adopted this idea from rail technology, in which pantographs have long been used to supply continuous power to electrically powered locomotives from overhead lines. This principle has also been used for road vehicles for more than 100 years. Conventional overhead line buses, known as O-buses or trolley buses, are supplied via pantographs. Electric highways are another example of supplying continuous power supply on roads. They have been implemented in pilot projects for trucks since May 2019 on the German autobahn A5 [1], and an implementation on the A1 is planned for the first half of 2020 [2].

So far, however, very few commercial vehicles have been prepared to use such electric highways, and they are generally test vehicles. Today, most pantographs are operated when the vehicle is stationary, so that they can be fast-charged at defined locations. In the area of buses, this is primarily done at central bus terminals or at end stations. But why are there different systems that are incompatible with one another geometrically or technically?

Overview of Pantographs

Today, the size and weight of a pantograph prohibit its use in passenger cars. Instead, to achieve higher charging power levels in passenger cars the focus is on optimizing the charging cable such as by adding water cooling. The batteries to be charged in passenger cars are typically smaller, so a lower power level often suffices.

Pantographs are available in different versions (Figure 1). One widely used variant is mounted on the vehicle roof, because this is the easiest to implement technically. It can be controlled by the driver, and during the charging process...
The behavior is somewhat different with the second variant known as the inverted pantograph. In this variant, the pantograph is part of the infrastructure. It is not lowered to contact the vehicle. In turn, the vehicle is only equipped with a rigid counterpart, the contact rails. It is necessary for the vehicle to automatically activate the drive control of the fixed structure to set the mechanism in motion. The above-mentioned CCS standard, which communicates solely by wire, cannot be used here, because the inverted pantograph must be controlled by a wireless connection. Although the ISO 15118-8 standard defines the communication medium as WLAN, it does not contain a detailed description of the information exchange. Version ISO 15118-20 includes an update for this, but this version has not been officially released yet. Nonetheless, the industry has taken efforts to establish a uniform method. Participants have agreed to use the OppCharge industry standard, which provides for power levels up to 600 kW. The standard utilizes a wireless point-to-point connection controlled via WLAN. The standard utilizes IEEE 802.11a, but 802.11n is referenced in ISO 15118. The ISO 15118-20

![Figure 1: Different pantograph versions and related communication technologies](image-url)

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Figure 1: Different pantograph versions and related communication technologies

its behavior is identical to that of a conventional Combined Charging System (CCS) plug. They both communicate over the same communication protocol based on IEC 61851 and ISO 15118. Such a pantograph can be added to existing CCS systems with just slight modifications. However, the challenge is to keep transmission line lengths for communication as short as possible. The Control Pilot (CP) transmits an Ethernet protocol over an unshielded single wire. However, this can lead to electromagnetic compatibility problems due to the high transmission frequencies involved. Because propagation of the powerline communication signal via radio transmission is possible with open lines, it must be assured that active communication only occurs between one charging station and one vehicle. A special protocol, SLAC (Signal Level Attenuation Characterization), is used to achieve this. At the end of the communication pairing process, it creates a network consisting of a virtual point-to-point connection. Messages from other charging stations or vehicles are then no longer received.

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![Figure 2: Differentiation of ISO15118, OppCharge and ISO15118-20](image-url)

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Figure 2: Differentiation of ISO15118, OppCharge and ISO15118-20
calls this technology ACD (Automatic Connection Device) which refers to the pantograph mounted in the infrastructure. Another basic difference (Figure 2) to the OppCharge standard is the architecture of the wireless connections. OppCharge recommends placing a separate access point on each charging mast to identify the vehicle at the charging point. However, it must be considered or ensured that radio channels of identical systems do not overlap. ISO 15118-20, on the other hand, mentions a possible architecture, but the standard does not exclude any other architectures.

In both cases, the wireless connection remains active, and therefore so does the charging protocol during the charging process. The existing contacts on the pantograph are all used: Physical Earth (PE) as a common ground connection, DC+ and DC− for the power transfer, and Control Pilot (CP) – based on IEC 61851-1 with a 1-kHz PWM signal – for detecting whether there is a conductive connection. Both OppCharge and ISO 15118-20 utilize a fixed duty cycle of 100 percent. Furthermore, the voltage at the CP contact, also known as the CP State, is evaluated and used according to the plug charging system and is transmitted to the charging station.

A third possibility is a horizontal pantograph. In this case, the vehicle has a large oval opening. The infrastructure docks the charging arm into this opening. Along with identical communication over CP and the missing PP, the mechanism for safe contacting is the biggest difference compared to the CCS plug and the two previously mentioned systems. To ensure that the connection between the charging station and the vehicle is maintained, the charging station applies a constant force on the vehicle via the charging arm. This assures an acceptable connection and thereby a successful charging process. In addition, an end contact switch in the vehicle confirms when the arm connection is fully engaged. Then communication can be set up with authentication.

Another variant is use of a wireless connection as the communication medium between the two nodes. As in the first two cases, the communication medium is switched from wired (roof-mounted pantograph) to wireless (inverted pantograph). These systems are therefore very comparable to one another with regard to communication and charging power.

Another relevant method is charging a vehicle by contacting from under the vehicle. One example is an inductive charging plate, which, however, is a completely contactless method. In underbody charging there is a moving component. Due to the lack of mounting space inside the vehicle, this moving part retracts into the floor and, when needed, travels upward to connect to the vehicle. From the perspective of the vehicle to be charged, this technology essentially behaves like an inverted pantograph. In this case, very little mounting space is needed in the vehicle. So, this concept for fast charging might also be of interest to the automotive industry. Similar to the inductive counterpart on the vehicle, just a small plate with contact points is needed on the floor.

Besides the geometric requirements of the four illustrative systems, weight, of course, also plays a significant role. That is because the less weight to be transported, the longer the theoretical driving range and larger the payload. Nonetheless, a pantograph mounted on the vehicle roof has its advantages: High reliability can be expected due to its sturdy and easy handling combined with the established, less susceptible communication over the CP. In addition, the susceptibility on the infrastructure side is lower due to the static mechanism.

Different Communication Technologies
The communication technology for the roof-mounted pantograph behaves identically to the plug charging of the Combined Charging System. Similarly, high-level communication for the horizontal pantograph is exclusively via the CP. However, the possibility of activation by a separate system is not excluded.

Nonetheless, a precise look at the wireless connection reveals certain challenges. WLAN is a very popular communication protocol for transferring information. But radio transmission is just as popular among hackers who could manipulate information with an attack. Considering these aspects, precautions are essential and must include encrypted message exchange. In the available OppCharge standard, wireless communication is protected over WPA2 (WiFi Protected Access), but encryption by Transport Layer Security (TLS) is not used currently. In ISO 15118-20, on the other hand, communication is protected by TLS Version 1.2 or higher to prevent external attacks. ISO 15118-20 calls for one-sided authentication. In this case, the communication controller in the vehicle (EVCC = Electric Vehicle Communication Controller) authenticates its counterpart in the charging station (SECC = Supply Equipment Communication Controller). However, the TLS standard makes it more difficult for developers to analyze data packets in the vehicle during testing, if there is no accessible debugging interface.

Also very important when using inverted pantographs is exact positioning which establishes the assignment of the vehicle to the charging point. For positioning, OppCharge
applies to the infrastructure producer. In terms of communication technology, suppliers and OEM’s are well equipped: Relevant standards are available and are continually being developed further. They provide a sound foundation for electric mobility in the commercial vehicle industry. In the end, it is the bus operators who must make a decision. They must decide early on, choosing a system that is most viable for the future.

Suppliers Are Responsible
Automotive OEM’s might leave clarification of standard functionalities to their suppliers so that they can rely on turnkey solutions. That is because: Each vehicle must be able to speak with any charging station. It is not just a single automotive OEM that is faced with this challenge, rather all of them equally. Interoperability of the systems is therefore very advantageous to all parties. To this end, specialized organizations and businesses offer the service of checking the two nodes for conformity to the standard.

Suppliers of the EVCC offer standardized solutions for this. For example, the Vector VC-EVCC-P charging controller (Figure 3) for roof and infrastructure pantographs is based on the OppCharge standard and will soon be available based on ISO 15118-20. Since it is a modular controller system, it is very easy to extend its functionalities, e.g., by adding plug charging.

Outlook
The pantograph as a means of fast charging is ideally equipped for establishing itself in bus services and municipalities. The only question is: In what form? That is because the systems described above are not compatible with one another. For automotive OEM’s, this means that support must be provided for all the usual variants. The same

Figure 3: Vector charging controller VC-EVCC-P and CAN-WiFi-Gateway for OppCharge applications

Translation of a German publication in Elektronik Automobilie 10/2020

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Literature References: