Chapter 6
Mobile Energy Storage Systems. Vehicle-for-Grid Options

6.1 Electric Vehicles

Electric vehicles, by definition vehicles powered by an electric motor and drawing power from a rechargeable traction battery or another portable energy storage system recharged by an external source, e.g. residential electrical systems or public electrical grids, are nothing new. Werner von Siemens developed and built his *Elektromote* in 1882 and Ferdinand Porsche his *Lohner-Porsche* in 1900, see Fig. 6.1.

In those days, electric vehicles reached ranges of up to 100 km and speeds of up to 105 km/h and employed the second most-used powertrain technology in vehicles after steam power. The advantage or rationale behind the high use of electric vehicles was the extremely advanced knowledge about electric motors and their reliability, as well as the presence of electricity systems in cities. Afterward, the development and refinement of internal combustion engines dealt electric vehicles a blow until they experienced a brief revival (1990s) because of various events (oil crises, government standards) and then a renaissance and renewed development from 2003 onward. Today, a typical electric car has a battery with nominal power between 8 and 30 kW and, in special cases such as the Tesla Model S, as much as 90 kW and a potential driving range, on one charge, between 100 and 220 km. This is very convenient and well-suited for city driving. Current reasons for the use and spread of electric today vehicles are generally the prospect of cutting fossil fuel use, boosting the efficiency of the entire energy chain (from production to consumption), cutting CO_2, and, in particular, optimizing the combination of two crucial infrastructures, namely, energy supply and vehicles, that are technically and economically on the basis of renewables.

A purely electric vehicle consists of a battery, a power inverter, an electric motor and a transmission, which collectively transmit the energy drawn from external connected energy sources or charging the infrastructure to the wheels. Depending on the components used, their features and designs, such as the type of electric motor, i.e., induction, synchronous or DC motor, it can achieve a total energy-conversion

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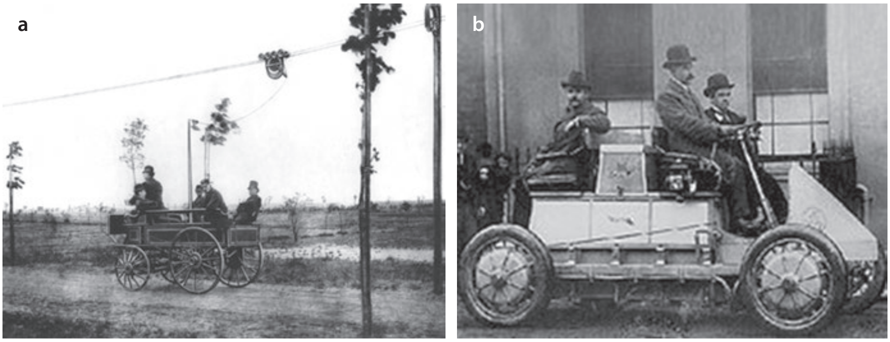

Fig. 6.1 The first electric vehicles: (**a**) Werner von Siemens [1] (**b**) Lohner-Porsche [2]

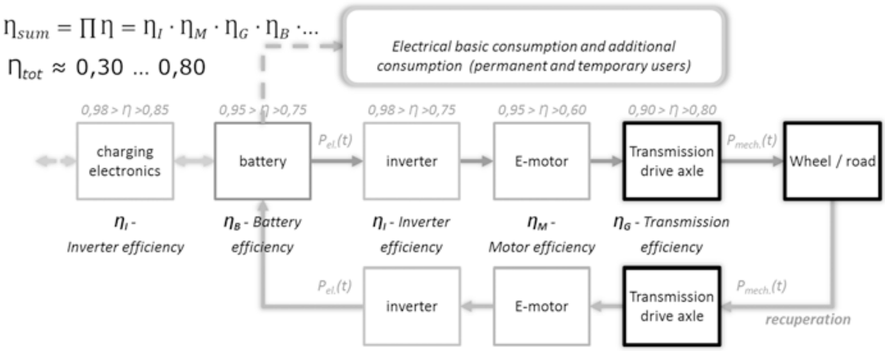

Fig. 6.2 Energy-conversion efficiency in the entire energy-conversion chain for electric vehicles [3]

efficiency of as much as 85 % in the energy conversion chain, constituting a highly efficient means of transportation (see Fig. 6.2).

Figure 6.3 depicts the progressively broader stages of electrification, from conventional vehicles with internal combustion engines and partly electrified power systems, up through purely electric vehicle. Hybrid electric vehicles (HEV) can be classified as parallel, series-parallel and series hybrids based on their powertrain topology. They do not have any option for connection to the grid to charge their energy storage systems. The vehicle battery is charged solely by recovery (regenerative braking) or by means of the internal combustion engine through an electromechanical converter (electric machine). The two motors (electric motor and internal combustion engine) of parallel hybrids effect the powertrain, providing the capability of parallel or single operation. The advantage of stepping is that the two motors can be designed as light duty units, additionally cutting weight and thus costs.

Series-parallel hybrids are characterized by a (step-less) combination of series or parallel mode corresponding to the driving conditions and direct mechanical connection of the two motors. Series hybrids on the other hand are characterized by

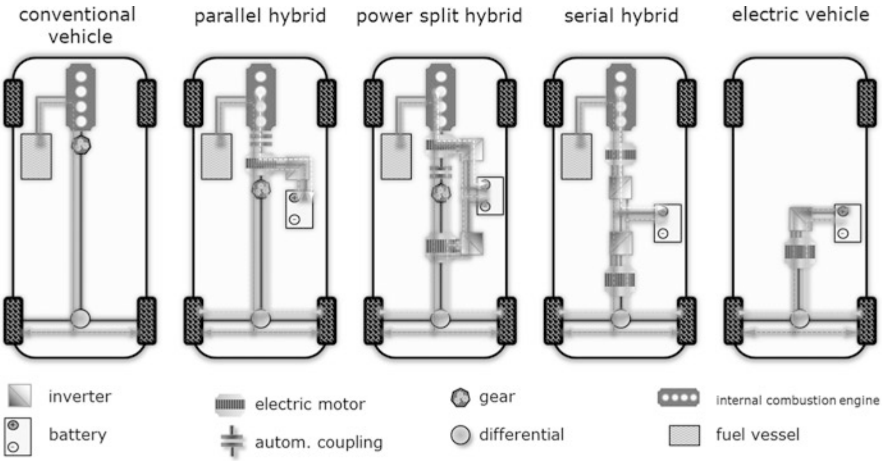

Fig. 6.3 Stages of electrification/powertrain topologies, of conventional through purely electric, vehicles [3]

repeated power conversion, the entire conversion chain thus attaining only moderate energy-conversion efficiency. Moreover, optimal operation is achieved by decoupling the combustion engine's rotational speed.

Vehicles with hybrid-powertrain technologies and an external grid connection are called plug-in hybrids.

The main component of an electric vehicle is its traction battery. Only chemical energy-storage systems are used in electric vehicles. This limited technology portfolio is defined by the uses of mobile traction batteries and their constraints, such as restricted weight, volume and safety criteria (transport). The conversion of electricity into chemical compounds constitutes one of the most widespread storage technologies, particularly for supplying power in the consumer sector (e.g., mobile devices) and for keeping the infrastructure running (e.g., telecommunications). Almost exclusively low-temperature and primarily lead-acid and lithium-ion batteries or high-temperature and primarily sodium-sulfur batteries, they are called internal storage systems since their energy level and output are interdependent.

External storage systems, on the other hand, have the advantage of independently sizable output and energy parameters. Both hydrogen/methane systems and redox flow batteries, which typically require more space, are representative of this group. The basic technical parameters of chemical storage systems are discussed in Sect. 5.6 and are compiled in Table 6.1 for mobile applications. Since they are generally connected to the grid by power electronics (now classified as rapid and reliable), this group of storage systems can cover a very wide range of use cases in electric vehicle and power-grid applications. Currently available energy storage systems and experiences have proven that lithium-ion systems are the preferred technology.

The various battery storage systems used in electric vehicles have characteristic charge curves dictated by technology or are powered by different charging processes, including constant current, constant voltage, negative pulse and so-called IU

Table 6.1 Technical parameters of chemical storage systems implemented in electric vehicles

Battery type	η %	Power density W/kg	Energy density Wh/kg	Self-discharge	P installation costs €/kW	E installation costs €/kW
Li-ion	to 95	100–185	120–200	5 %/month	150	180–600
Redox flow	to 5	N.A.	30–70	0.4 %/day	1500	150
NaS	to 75	250	200	10 %/day	200	150–600
H_2/methane	to 40	1000	580–33,300	<1 %/month	2000	6

charging. Based on the application and various strategies that control current and voltage, they achieve the goal of fully charging a battery within its operating limits.

Another component, the inverter, adjusts attributes of the grid parameter (voltage, current) and is responsible for converting them bi-directionally from AC voltage to DC voltage, i.e., for so-called charging and powertrain systems. This inverter is based on power electronic components that can have various circuit topologies depending on the requirements and type of electrification, see Fig. 6.4. The standards for such components that can be used in the automotive sector are very strict and have to be met all the time. These include:

- ambient air: –40–135 °C
- single circuit water cooling system: –40–105 °C (120 °C when power is reduced)
- overall life: 20 years
- service life: 10,000 h
- passive temperature cycles @ ΔT 100 k (15 years with two cold starts every day): 10,000 cycles

Each circuit topology has certain concrete advantages and disadvantages. A B6 full bridge with a bidirectional DC/DC converter and an HF transformer, for instance,

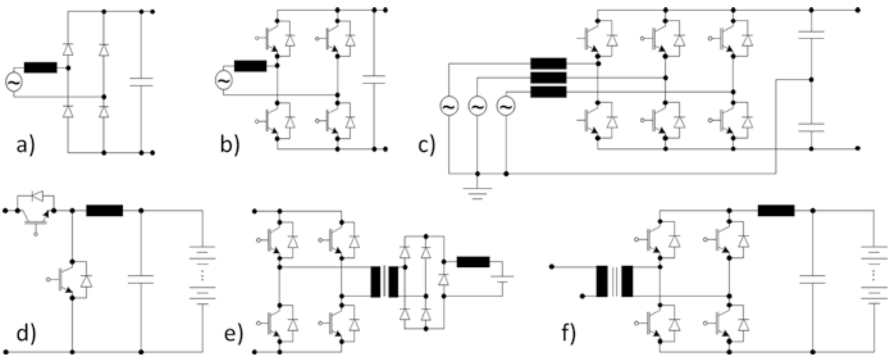

Fig. 6.4 Typical circuit topology of unidirectional and bidirectional chargers,(**a**) B2U input rectifier, (**b**) H bridge,(**c**) B6C full bridge,(**d**) bidirectional DC/DC converter, (**e**) DC/DC converter with an HF transformer,(**f**) bidirectional DC/DC converter with an HF transformer

Table 6.2 Comparison of the characteristics of electric motors used to power vehicles

	ASM	SM	GRM
Torque	0	+ +	0
Speed stability	+	0	+ +
Losses (driving cycle)	+	+	+
Costs	+	−	+ +
Reliability	+ +	+	+ +
Technology maturity	+ +	+	0

has comparably low energy conversion efficiency and high component complexity but advantageous galvanic isolation through the transformer and therefore always ought to be analyzed and assessed separately according to the design.

Electric motors, one of the links in the energy chain in electric vehicles, can be broken down into the following three groups:

- DC motor (DCM)
- synchronous motor (SM)
- induction motor (IM).

The motors in electric vehicle can be constructed as one central motor or as a distributed powertrain, e.g., a hub motor. DC motors have a simple control system that performs fast and simple operations but are extremely prone to wear caused by consumption of the carbon brushes installed. Permanent-magnet or brushless synchronous motors wear little but are expensive because of their magnetic materials/rare earths and therefore have to be evaluated from case-to-case/vehicle-to-vehicle. Induction motors are easily manufactured electric motors but are significantly larger than other motors. See the comparison of other features of electric motors in Table 6.2.

The transmission, the final link in the energy chain in electric vehicles, see Fig. 6.2, adjusts the speed between the motor and wheels and the torque between motor and wheels. It can be adapted to various different transmission models from manual to automatic, depending on the stage of vehicle electrification and powertrain function (electric driving, stop-start operation, efficient recovery, support function, unnoticed start of the internal combustion engine, electric all-wheel drive).

6.2 EV Standards and Technologies for Power and Transportation Systems

More than 300,000 electric vehicles were on the road worldwide in 2014. Assuming that the average battery capacity is 30 kW, this constitutes a flexible energy storage system capacity of 9 GW. Leaders are the USA (174,000 electric cars) and

Japan (68,000 electric cars), followed by China (45,000 electric cars) and Germany (17,500 electric cars). Diverse studies and analyses project a continual rise in the development of electric vehicles (see Fig. 6.5), thus multiplying the number of electric cars in the coming years and substantiating the tremendous potential to expand the flexible use of mobile storage systems [5].

Present-day electric vehicles are principally compacts, standard products with a range of up to 200 km and varying consumption per 100 km. Intended for short and medium-distance trips, their battery capacity ranges from a few to 80 kW, see Table 6.3.

These basically newly developed electric vehicles only recently became marketable and are increasingly being introduced on the road as standard products. They are an appropriate size since the average period of car use in Europe is around 60 minutes, around 80 minutes in Germany, and only 13 minutes in Latvia. The estimated average distance driven per trip is 33 km per person and day, 41 km in Finland and only 8.7 km in Latvia, and each country has to be considered as infrastructure-specific, see Table 6.4 and [23]. This reveals that electric vehicles' vast numbers and lower power ranges endow them with tremendous potential for use in energy supply systems and various use cases, either as small energy producers or storage systems. This property is reinforced by private ownership of mobile energy storage units/traction batteries and the fact that electric vehicles are parked most of the day and are not at those times used for transportation.

Making electric vehicles suitable and usable for the road (Motor Vehicle Code), as well as the electrical grid (grid connection, grid operation), necessitates modifying or upgrading various different standards and guidelines, which have to be defined both nationally and internationally, and would require a great deal of time.

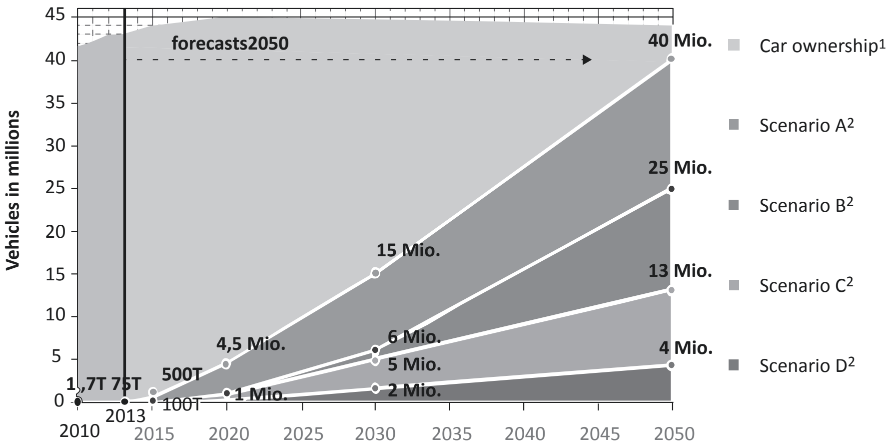

Fig. 6.5 Worldwide growth in the number of electric cars 2010–2050 [3]. Sources [1,2] Jan Richte, Ditmar Lindenberger (2010) EWI Institute of Energy Economics the University of Colonia[3]; Carolin Richter (2009) Electric mobility—opportunities, challenges and contribution. First German Electro Mobility Congress. Bonn 16–17 June 2009

Table 6.3 State-of-the-art electric vehicles

Vehicle	Picture	Range [km]	Consumption [kWh]
AUDI A3 e-tron	 [13]	50 km electric+890 km with range extender	11.4 kWh/100 km, 1.5 l/100 km combined
BMWi3	 [10]	190 km	12.9 kWh/100 km
Citroen Berlingo	 [11]	120 km	21.0 kWh/100 km
Citroen C-Zero	 [11]	150 km	12.6 kWh/100 km
Ford Focus Electric	 [12]	162 km	15.0 kWh/100 km
Kia Soul EV	 [12]	212 km	14.7 kWh/100 km
Mercedes B-Klasse Electric Drive	 [14]	200 km	16.6 kWh /100 km
Mitsubishi i-MiEV	 [15]	150 km	13.5 kW h/100 km
Nissan e-NV 200	 [16]	170 km	no information
Nissan Leaf (2012)	 [17]	175 km	17.3 kWh/100 km
Opel Ampera	 [18]	83 km electric + 420 km range extender	16.9 kWh/100 km, 1.2 l/100 km com bined
Peugeot iON	 [19]	150 km	12.6 kWh /100 km
Renault Kangoo Z.E.	 [20]	170 km	14.0 kWh /100 km

Table 6.3 (continued)

Vehicle	Picture	Range [km]	Consumption [kWh]
Renault ZOE (2013)	 [20]	210 km	14.6 kWh /100 km
Smart fortwo electric drive	 [21]	145 km	15.0 kWh /100 km
Tesla Model S 90D	 [22]	560 km	no information
Volkswagen e-Golf	 [9]	190 km	16.7 kWh/100 km
Volkswagen e-up!	 [9]	160 km	11.7 kWh /100 km

Table 6.4 European car parameters [8, 23]

Country	Average number of rides per person and day	Average kilometerage per person and day (in km)	Average driving time per person and day (in minutes)
BE	3.0	n/a.	n/a
CZ	n/a	21.9	n/a
DK	3.0	37.3	n/a
DE	3.3	36.9	80.0
EE	n/a	37.3	n/a
ES	1.8	n/a	44.4
FR	2.9	35.3	58.2
LV	1.9	8.7	13.0
NL	3.1	31.9	59.9
AT	3.0	28.1	68.8
FI	2.9	41.8	70.7
SE	2.7	44.1	62.6
UK	2.9	31.8	63.3
CH	3.6	37.1	84.5
NO	3.3	37.9	68.2

However, this book includes and describes only those aspects required to ensure their operation as mobile energy storage systems for electrical grids and the options to make them compliant for this purpose. Figure 6.6 defines the trends/scopes of standards/interfaces that apply to the actors and components used, such as [6]:

- Vehicle—charging infrastructure
- Vehicle—driver
- vehicle—energy market
- charging infrastructure—grid
- charging infrastructure—energy market
- charging infrastructure—charging infrastructure operator
- charging infrastructure operator—billing service
- driver—billing service
- driver—charging infrastructure (e.g., reservation of public charging stations)
- charging infrastructure operator—driver
- vehicle—service
- vehicle—billing service

The standards for reliable operation and the capability of flexible use of energy storage systems have to be derived from each of the interfaces/sub-processes. This book only examines the topic of vehicle-charging infrastructure interface and the

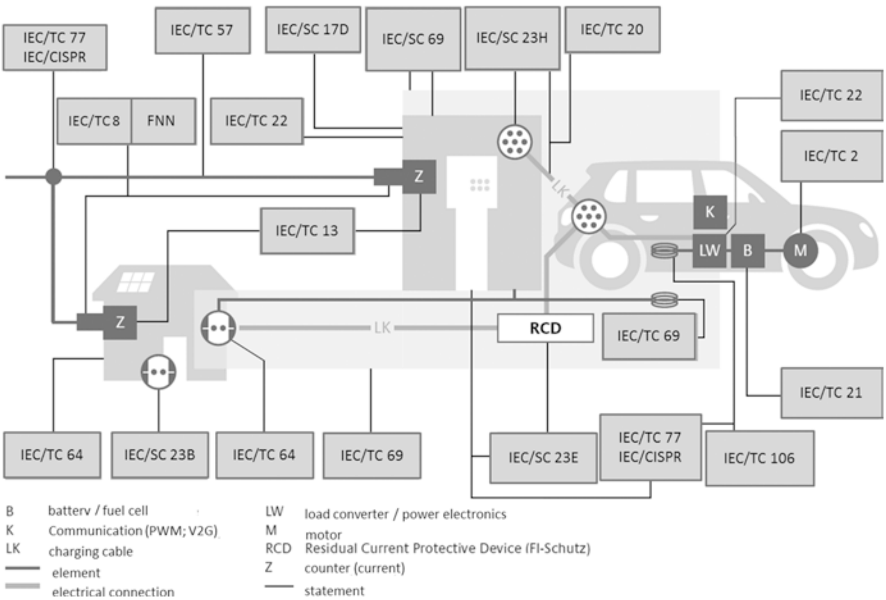

Fig. 6.6 DKE (German Commission for Electrical, Electronic and Information Technologies of DIN and VDE) and IEC (International Electrotechnical Commission) standards committees relevant to electric vehicles [6]

charging infrastructure more closely since it is essential to the flexible use of energy storage systems.

The form of energy and data exchange between charging stations and vehicles, as well as vehicles and charging stations (energy recovery), is contingent on the type of connection between these components, see Fig. 6.7 [4]. A distinction is usually made between classic plug-in and inductive (wireless) systems. Battery replacement systems, i.e., complete and fast battery- system replacement, can also be considered here. Plug-in systems establish a physical connection between a vehicle and a charging station, which can be differentiated by the type of voltage used. AC charging stations transmit power to a vehicle by AC voltage, which is inverted by a battery charger installed in the electric vehicle. The advantage of this system is generally the widespread use of low-voltage AC equipment, which is powered by "lower" voltage and thus also provides certain component savings (cost, weight), e.g., a rectifier does not have to be installed in the charging station. The disadvantage of AC charging technology is basically the capability of transmitting only limited power. Typical single-family household installations have a power supply of up to 16 A, providing a maximum of 11 kW of power for a three-phase connection. While it can be upgraded up to 63 A, i.e., 44 kW, this requires investing in the existing electrical infrastructure, and this is implemented as an extra option only in certain cases. DC charging technology generally has the advantage of the capability to transmit high power of >50 kW to very high power of 200 kW, e.g., Tesla S, and thus of charging a vehicle battery quickly, but this requires special components (i.e., a rectifier in the charging station and a DC-DC converter in the vehicle) including protective relays, which are quite expensive.

Inductive charging systems have a significant advantage over plug-in systems, namely, they do not need to have or use a cable or connector, and are therefore

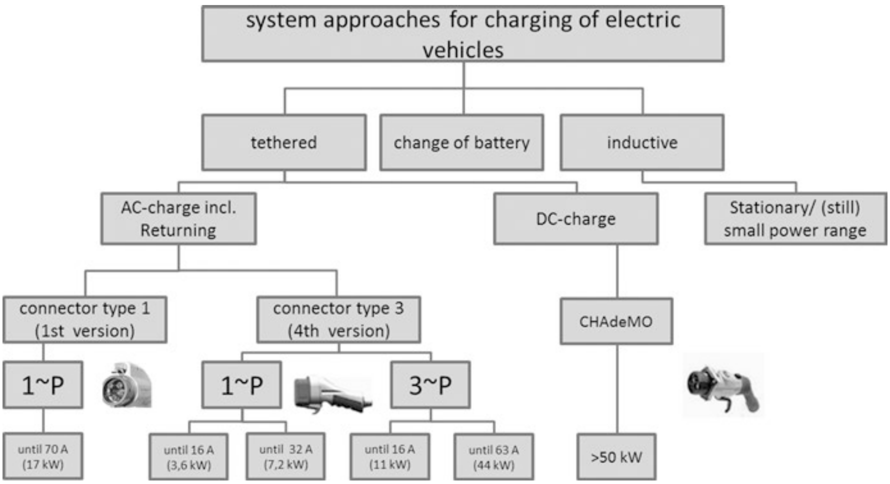

Fig. 6.7 Electric-vehicle charging systems [4]

primarily used in in the premium electric-vehicle class. The disadvantage of such systems is their inability to transmit more power than AC/DC charging technologies, i.e., up to 3.6 kW (technologically required by, among other things, potential spacing between coils and electromagnetic compatibility).

The alternative to fast charging technologies (high DC and AC power) is a battery replacement station. Batteries are preplaced to enable a procedure lasting a few minutes, the battery having been charged 100 % for use at this time. The disadvantage of this method is that it can frequently stress the mechanical contact of the battery terminals and thus reduce a battery's service life. These methods require tremendous charging power and capacity, which have to be provided at the replacement station. The issue of standardization is just as complex, e.g., questions about size and type of connection have to be answered.

Depending on the technology, diverse connector systems exist, which connect a charging cable and charging station with a vehicle. They have been proposed from the perspectives of various manufacturers' specifications and cannot yet be viewed as definitive standard systems, see Fig. 6.8. Experience with this, as well as their compact designs, has made the so-called Type 2 connector, or one and three-phase charging in compliance with the standard series IEC 62196, preferred for AC charging and the most widely established approach in Europe. Largely developed by Mennekes for AC charging and therefore also called a Mennekes plug, the Type 2 connector has three line contacts (L1, L2 and L3), a contact for the neutral conductor and a contact for the ground contact. It also has a proximity pilot (PP) contact, which detects the presence of the connector and defines the cable configuration/cable thickness by measuring resistance, and a so-called control pilot (CP), which ensures that charging signals and exchange control signals are sent between electric vehicle and charging station by so-called pulse-width modulation (PWM). Moreover, the Type 2 connector has two additional pins for fast DC charging and is classified as a so-called Combined Charging System (CCS) for European and American DC charging standards.

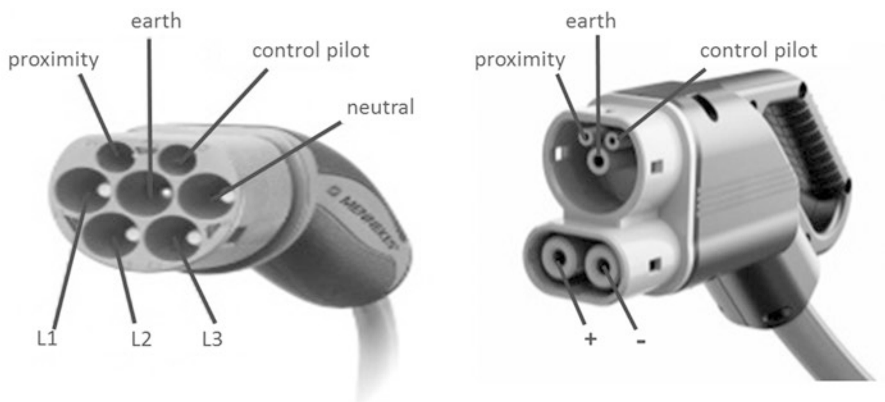

Fig. 6.8 Typical connector systems—AC charging (Type 2) and DC or AC and DC charging (CCS)

This connector's pilot contacts and the neutral conductor are used for safety and communication between a charging station and an electric vehicle during charging at fast DC-charging stations and are equivalent to the AC connector type. Only the bottom two thicker DC contacts are used for DC current. The DC extension for Type 1 and 2 connectors was jointly developed by the various committees in order to preclude different standards, as is the case with AC charging [4].

Regardless of the charging technology and use case, flexible use of mobile energy storage systems necessitates establishing interoperability among components such as vehicles and charging stations, as well as higher-level systems in order to exchange data on ongoing processes and components (e.g., vehicle condition, battery state of charge, temperature) and to execute commands/actions (controlled/dedicated charge/discharge curves) for the purpose of controlling technical and economic responsiveness. Attention must be paid to two standards relevant to the electric vehicle-charging station interface:

- IEC 61851
- IEC ISO 15118

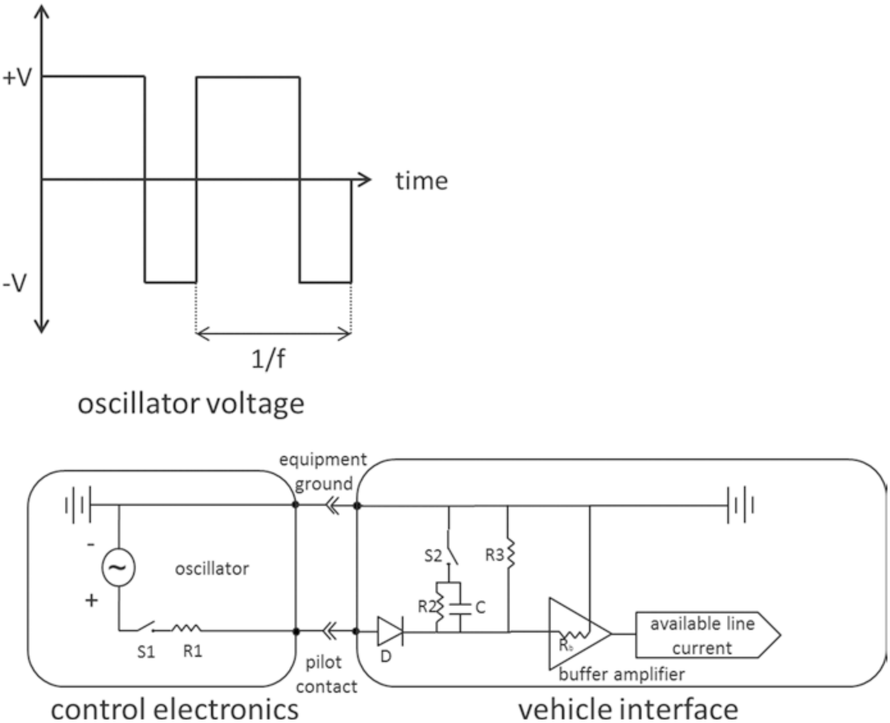

Fig. 6.9 Typical pilot circuit in an electric-vehicle system [24]

Part 1: Electric Vehicle Conductive Charging System—General Requirements of the standard IEC 61851 Electrical Equipment in electric road vehicles addresses general system standards and interfaces, protection against electrical shock, connection between power supply and electric vehicle and special requirements of vehicle launches and connector systems [24]. It defines basic charging modes, which, depending on their design, are essential to the implementation of electric vehicles as responsiveness option for smart grids:

- Charging mode 1: Connection of an electric vehicle (one or three-phase) by means of a standard socket-outlet for rated current up to 16 A
- Charging mode 2: Connection of an electric vehicle (one or three-phase) by means of a standard socket-outlet together with a control pilot between the electric vehicle and the plug or control unit and cable
- Charging mode 3: Direct connection of an electric vehicle to the AC grid employing a control pilot, which is always coupled with the system connected with the AC grid
- Charging mode 4: Indirect connection of an electric vehicle to the AC grid employing an external charger, the control pilot always coupled with the system connected with the AC grid

Regardless of the charging mode, with the exception of charging mode 1, the following functions and standards have to be met or ensured at all times:

- verification that the electric vehicle is properly connected (connection verification),
- continuous monitoring of the ground (by measuring the flow of current in the control pilot),
- activation and deactivation of the system (authorization for activation and safety for deactivation as a function of the status of the pilot circuit), and
- selection of the charge current (maximum power rating)

What is more, charging mode 1 does not involve any data communication. Charging modes 2 and 3 have freely selectable serial data communication. Such communication is mandatory for charging mode 4. In this standard, the pilot circuit in the plug-cable-socket system is the sole control system for use as a flexible mobile energy storage system, which is implementable in charging modes 2, 3 and 4 as soon as the pilot circuit has been designed properly (See the typical design in Fig. 6.9) [24].

The greatest continuous current supplied by the power supply system to an electric vehicle can be ascertained and controlled by an appropriate ratio of pulse-width modulation, thus making it possible to exchange power among components flexibly, too. Such so-called controlled charging/available line current is directly proportional to the duty cycle with a constant of 0.6 A/% of the duty cycle of 5–80 % (see Fig. 6.10) and can be used, to a certain extent, to control a mobile energy storage system/traction battery flexibly by external factors/functions, e.g., smart-grid use. This kind of controllability of a battery is quite complex and sensitive, however,

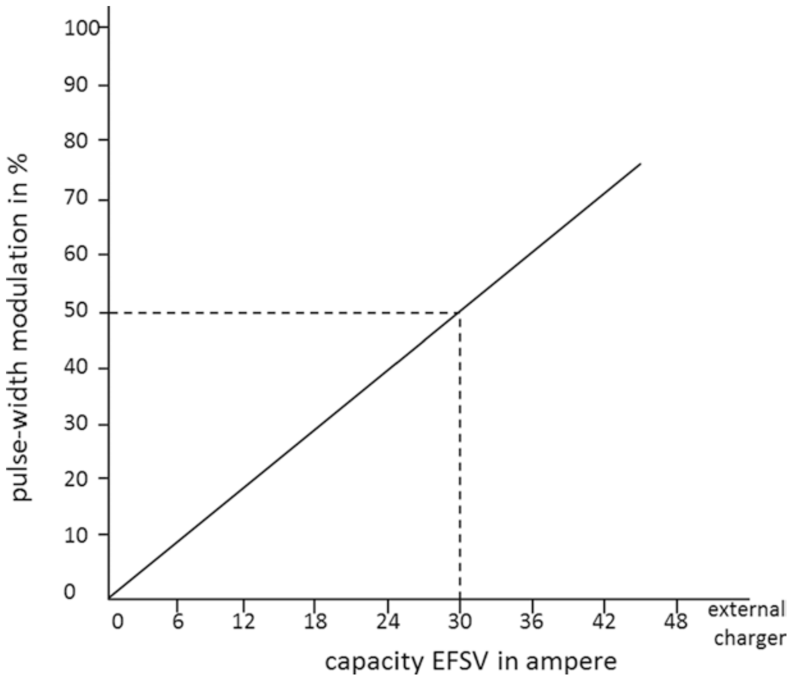

Fig. 6.10 Power supplied as a function of the pilot-circuit's duty cycle in compliance with IEC 61851 [24]

and a complete electric-vehicle system based on this does not permit other essential functions, e.g., personal identification or business logic such as dynamic price transmission and charging schedules or protective functions such as data encryption, or cannot meet their requirements such as speed, data performance and reliability.

For these reasons and because of the requirement to model systems among electric vehicle and external systems and their interactions and functions completely, ISO IEC 15118 Standard: Road vehicles—ehicle to grid communication interface was developed in 2013. ISO/IEC 15118 specifies the communication between electric vehicles (EV) and the electric vehicle supply equipment (EVSE) [25–27]. The communication components of this equipment are the electric-vehicle communication controller (EVCC) and the supply equipment communication controller (SECC). Communication is defined by two different concepts, namely, "basic signaling" and "high-level communication". ISO/IEC 15118-1 and ISO/IEC 15118-2 specify "high-level communication". The relations between these two concepts are specified in ISO/IEC 15118-3. The standard ISO/IEC 15118 specifies high-level communication between electric vehicles and charging stations [ISO/IEC 15118-2] and especially the types of messages, their particular format and, finally, the communication procedure in conformance with standards. Established systems are used to ensure the necessary generalization; a PLC modem provides an Ethernet connection for communication using the IP. The IP packets contain the messages specified by ISO/IEC 15118.

The standard's key points are condensed concretely in general requirements:

- High-level communication can be used to provide functions such as identification, payment and expanded additional services.
- Data communication between electric vehicles and other actuators/components must be treated confidentially, thus requiring such integrated mechanisms as security and safety functions (protection against monitoring, manipulation, replay attacks and hacking).
- Electricity supplied by the charge-spot operator must either be measured specifically in the EVSE or be part of overall energy consumption, and different billing options defined by the energy providers must be factored in or permitted.

The standard additionally defines the specific requirements of the various actors such as users, utilities and OEMs. The entire range of the standard's uses is elucidated by a description of the groups of actors, distinguishing between primary and secondary actors (see Fig. 6.11). Primary actors are directly involved in the charging process [25–27].

The information flow between an electric-vehicle communication controller and a supply-equipment communication controller is specified in keeping with all of the layers of the Open Systems Interconnection (OSI) reference model. The actors perform various functions, such as starting and stopping charging, identification, authentication and payment, as well as monitoring the system for faults, e.g., power cable faults.

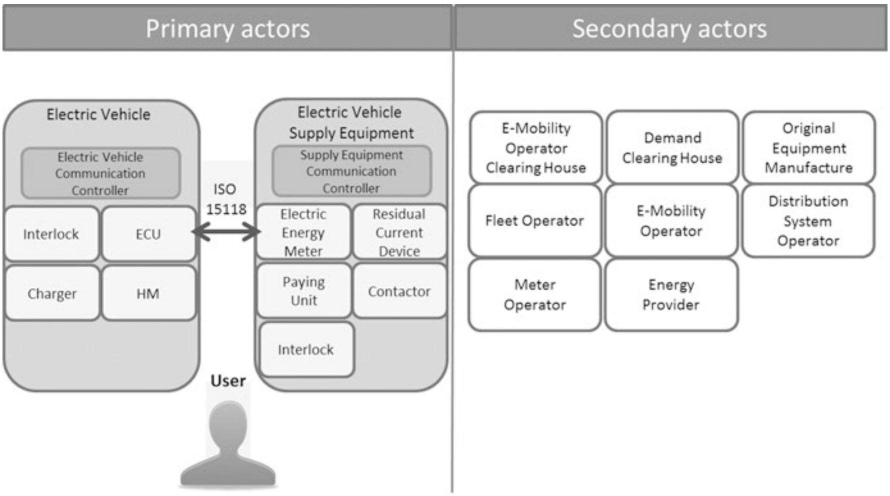

Fig. 6.11 Overview of primary and secondary actors according ISO IEC 15118 [25]

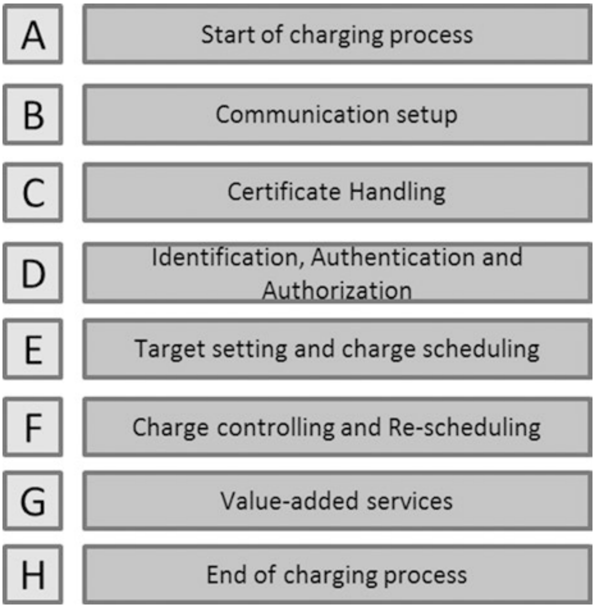

Fig. 6.12 ISO IEC 15118 use-case function groups [25]

ISO IEC 15118 breaks electric-vehicle system charging and discharging down into eight functional groups and resultant preliminary use cases (see Fig. 6.12): initialization of the process (i.e., verification of features such as the presence of PWM and high-level communication), communications setup (i.e., establishment of proper communication required between electric vehicles and charging stations), certificate handling, identification (authentication and authorization by RFID or credit card, for instance), charge-curve plotting, controlled charging and discharging and completion of charging. The actors involved and the procedures are specified for each of these scenarios. The potential combinations, i.e., the implementation of the standards in a vehicle and/or in a charging station, are differentiated. For instance, when ISO IEC 15118 has not been implemented in the charging station, but has been implemented in the vehicle, charging can only be done by following the standard IEC 61851, i.e., it is very rudimentary. On the one hand, the standard ISO IEC 15118 covers an extremely wide range of flexible uses for mobile energy storage systems, e.g., a vehicle-to-grid support use case (active power control, no allowance being made for reactive power control and frequency stabilization actions) and covers the complete range of services (e.g., authentication) and functions (agreement on charging criteria, encryption), thus making it indispensable for the flexible use of energy storage systems. On the other hand, it has not been implemented in all electric vehicles, and it is not yet widely in use since continued work on the standard and its parts is hindering its uniform use.

Charging Infrastructure and Electrical Grid Standards

Regardless of the charging technology, the charging station is an element essential to ensuring flexible energy and data exchange when servicing electric vehicles. It must meet interoperability standards for vehicle connection, as well as different standards resulting from such use cases as:

- private, semi-private, public or semi-public charge spots,
- outdoor, covered or indoor charge spots,
- fast charging on the road or charging at "relatives' one-phase household sockets", and
- analyzing and performing billing (individual billing, aggregate billing, direct payment), e.g., as defined in Germany's so-called National Platform for Electric Mobility.

Generally, every charging station contains five function/component groups (component installation, communications components, components grid connection, vehicle connection components and user interface components) which, depending on the use case, can be combined in various ways, based on their complexity and potential services (see Fig. 6.13) [7]. A charging station consists of internal

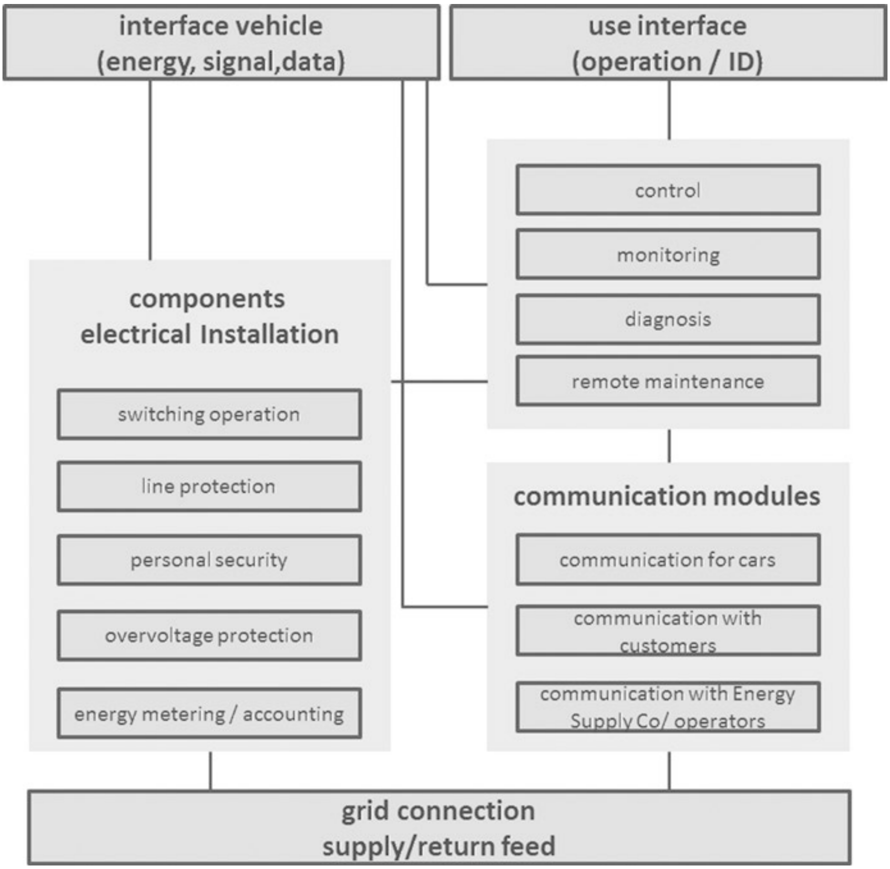

Fig. 6.13 Block diagram of a charging station [7]

components and external components, which exchange energy and data. Communication with electric vehicles has been described in the preceding section. Communication with the electrical grid and its standards is examined here and is dominated by the development and conversion of the energy supply system. The growing addition of renewables throughout various levels of the grid (the low-voltage level on which electric vehicles are connected, and the medium- and high-voltage levels) in many regions is resulting in bidirectional power flows and, under certain circumstances, can overload the electrical grid. Such new situations are making it necessary to equip even the lower levels of the grid, e.g., high-, medium- and low-voltage systems, in response to the attendant challenges since (metering and control) equipment has been lacking there in particular and new components, e.g., renewables as well as stationary and mobile energy storage systems, are being added there more than on the communication level of the grid.

Meeting these demands, continuing to maintain high system reliability with every component, and making new system services possible requires developing and establishing information and communications technologies (ICT) that are subject to technical and economic control mechanisms. This is the only way to coordinate and optimize operation of the energy-supply system with all of its facets, functions and components, e.g., electric vehicles, and based on, among other things, integrative data management. Since energy systems currently lack the ICT infrastructure necessary throughout all levels of the grid to perform various functions, either existing systems will have to be upgraded, especially in transmission systems, or new dedicated solutions will have to be developed, especially in medium- and low-voltage grids. A model of complete ICT architecture (see Fig. 6.14) is based on bidirectional data communication, thus enabling the system operator to analyze the system data, by monitoring data from meters and controllers online and to take appropriate action.

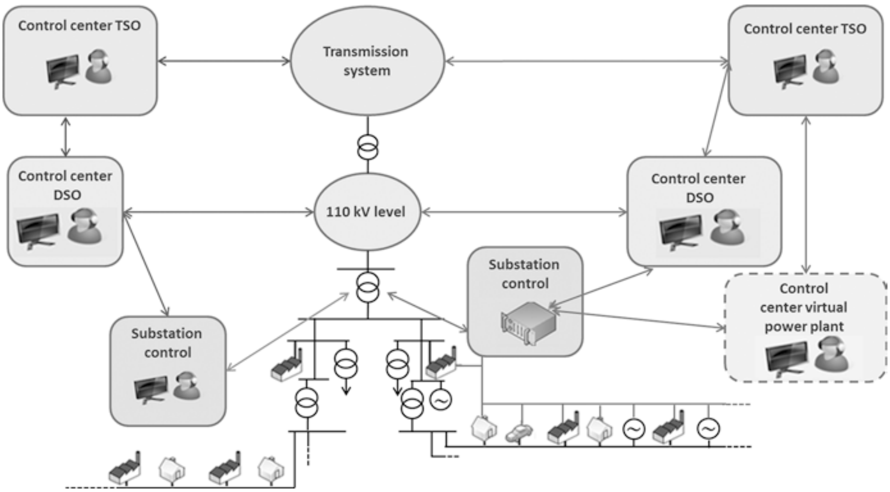

Fig. 6.14 Present and future ICT infrastructure for an energy-supply system [28]

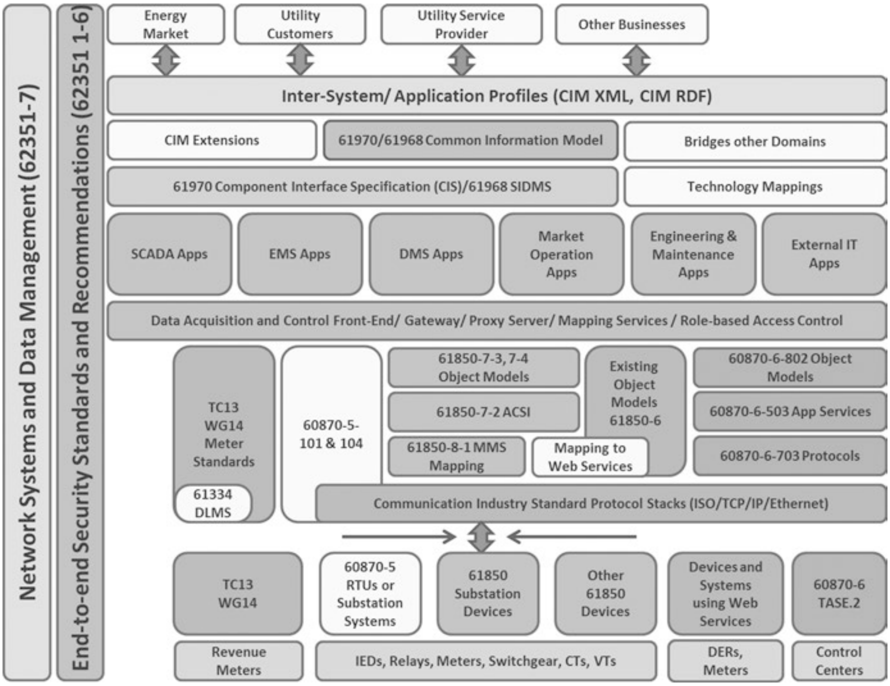

Fig. 6.15 Reference smart grid architecture [28]

Pertinent ICT standards for smart grids define the standards for interfaces and data models and additionally cover aspects of data and information security.

The IEC TC 57 (TC 57) committee has developed a complete standard architecture including communications standards (see Fig. 6.15). This architecture consists of standards assigned to each level of the system, from operations with limited quantities of data but fast communications (bottom of the graphic) through standards that address large quantities of data (top of the graphic). The three standards (i.e., IEC 61850, IEC 61970 and IEC 61968) in particular are indispensable to expedient implementation of, among other things, electric vehicles as responsiveness components.

IEC 61850 Substation Automation

This standard consists of several parts originally developed to standardize protective processes in automated substation systems. Since its modularity and transferability made the concept applicable not only to protection but also universally, it was enlarged for the entire power system and its components.

The individual parts of the standard specify the entire approach to digitizing automated processes and conformance tests, but they also focus on data exchange and services and standard configuration, as well as data mapping between various components and systems.

The advantage of uniform standards such as IEC 61850 over the standard IEC 60870 is its standard semantics, which, for instance, permit vendor-neutral data exchange (the individual interface fields having manufacturer-specific features). One distinctive feature of IEC 61850 is that standard mapping of services makes it possible to implement ready for use solutions. This is particularly relevant for mobile energy storage systems.

IEC 61968 and 61970, Common Information Model

Unlike the standard IEC 61850, the standards IEC 61968 and 61970 focus on the interfaces in energy-management systems. Both series of standards are intended not only to define the data models for the technical features and functions of energy-supply systems and their components, but also to make it possible to map business processes so that data systems can be connected with energy-market mechanisms, for instance. The standard IEC 61968 includes the distribution system. The basis for both standards is the Common Information Model (CIM), which employs object-oriented modeling of elements and processes and is based on Unified Modeling Language (UML). Certain classes, i.e., attributes, are defined and these classes are subsequently assigned to packets. What is more, CIM standards can be used to make upgrades independently. This is a very important aspect for new components and functions, in particular.

IEC 62351

The standard IEC62351 specifies the mechanisms that protect the ICT infrastructure in an energy-supply system from scheduled and unforeseeable events. It consists of a variety of parts but concentrates on data security, integrity, availability and detection, some parts of the standard still being in development. Since disruptions caused by ICT can compromise or cripple a system and its parts, and functions, this standard will play a major role in the future.

6.3 Electric-Vehicle Networks as Energy Storage Systems in the Power and Transportation System

Electric vehicle networks can only become established when they constitute a system capable of interconnecting all of the actors and components involved and the attendant electrical and transportation system infrastructures, through the information and communications infrastructure and of integrating the diverse infrastructure standards. It must evolve from a mobile energy storage system with limited controllability into a fully intelligent system that can be integrated in the energy system very flexibly and, for instance, respond to the volatility of renewable-energy production without curtailing transportation needs, see Fig. 6.16.

The respective infrastructure levels (electrical grid, transportation system and information and communications technologies) should not only perform the tasks of their own infrastructures but also facilitate value-added services for other levels. The electrical grid infrastructure is chiefly responsible for the security and

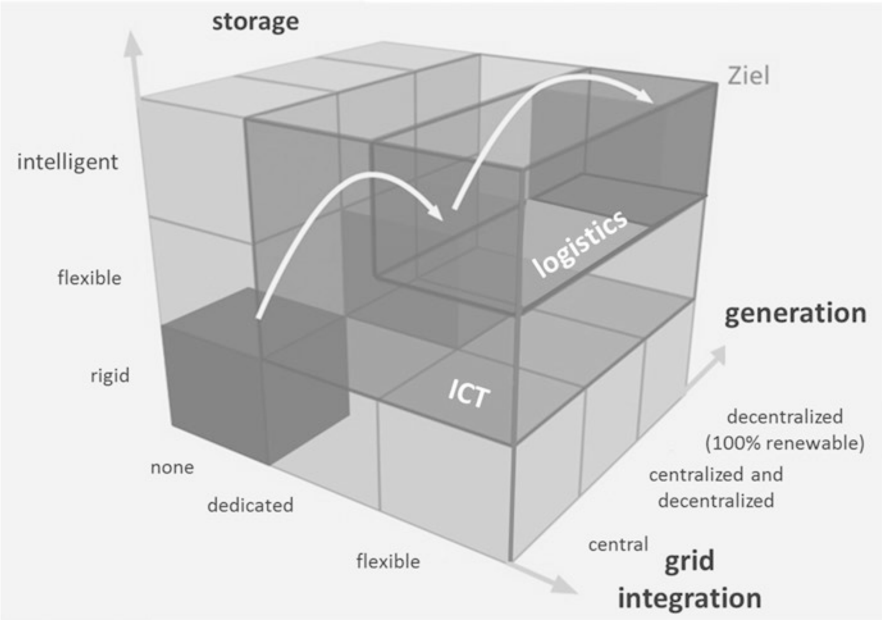

Fig. 6.16 Stages of development and infrastructures of an electric-vehicle network [29]

reliability of the energy supply, i.e., continuously balancing consumption and production while also factoring in the increasing and very flexible load/storage system (electric vehicle network). Primarily, connections with renewable-energy source are preferred, especially for the purpose of zero-emission electric-vehicle networks.

The controllable processes, integrated information and data exchange, and so-called controlled charging and discharging can be used to implement so-called vehicle-for-grid plans in which, on the one hand, electric vehicles can serve the electrical grid in vehicle-to-grid applications such as dedicated and selective active- and reactive-power supply and, on the other hand, electrical grids provide electric vehicles special services in grid-to-vehicle applications. Furthermore, forecasting of renewable-energy production and consumption (stationary and mobile), as well as the continuous supply of data (e.g., on the charging process, charge status) that is relevant to metering and processes in an electricity-supply infrastructure, deserves particular attention and plays an important role in the optimized implementation of electric-vehicle networks. The transportation infrastructure is fundamentally occupied with the typical tasks of ensuring transportation and with the definition siting and provision of appropriate charging stations to guarantee continuous and attractive electric transportation. Technical aspects, such as security and functions of charging stations contingent on the site of installation (public, semi-public, private), are taken into account and the consequences for unrestricted access to, and assurance of, electric transportation are factored in. From the perspective of electric vehicles, operation of a transportation infrastructure necessitates continuous communication of relevant information, such as vehicle SOC (state of charge) or power requirements,

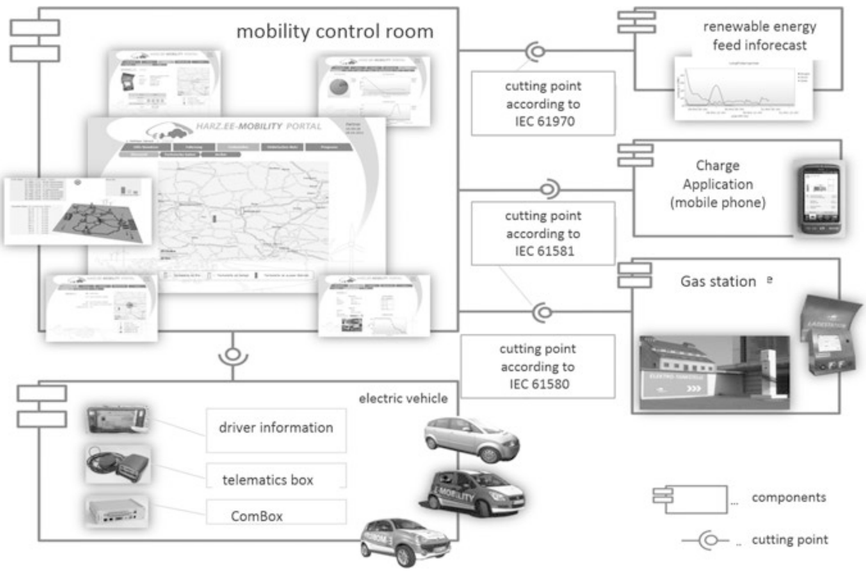

Fig. 6.17 Electric-vehicle network components and interfaces in the Harz. EE–mobility research project [29]

in order to meet customer demands and to be able to provide essential services (charging-station reservations, free charging-station searches). The information and communications infrastructure in an electric-vehicle network has the job of securely and reliably transmitting and providing all essential data and information from status information on existing communications connections to charging stations by user authentication, billing of charging, and parameters measured in the electrical grid and business processes. Moreover, every electric-vehicle network has a central data-management-and-decision tool, see Fig. 6.17, into which all information on the entire infrastructure flows continuously and out of which actions and control signals derived from it are sent to individual components. Depending on their role in the system, actors can retrieve and access data. Charge-point operators retrieve data related to charging in their charge-point network or transportation-service providers collect the electric-vehicle fleets' power requirements for the next 24 hours. End users, i.e., electric-vehicle drivers and owners, have other options such as driver-information systems and cell-phone apps at their disposal to monitor and interact with processes. A use-case description is usually prepared for every use case and contains other information, such as a brief description of the use case, the actors involved, trigger events, outcomes, input data, output data, preconditions and post conditions, general process descriptions and non-functional requirements. Based on the use cases, the systems architecture was broken down into systems components that are involved in the use cases and perform various jobs. This creates a complete electric-vehicle network architecture specifying all functions, their actors and options, which are used to define the standards.

Test Questions Chap. 6

- Why should we use e-mobility; what are the benefits and disadvantages?
- What components make up an electric-vehicle system?
- What are the various kinds of connectors between e-cars and charging stations?
- What types of information and communication technologies (ICT) and channels are needed to realize the e-mobility system?
- What kind of services can e-mobility provide in the power system?

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