Which new semiconductor technologies will speed electric vehicle charging adoption?

Texas Instruments

Bart Basille,
Systems Architect
Texas Instruments

Jayanth Rangaraju,
Systems Manager
Texas Instruments

Everyone loves the idea of an electric vehicle (EV). They are silent, nonpolluting and offer excellent performance. But their high prices and technical limitations have kept them from becoming a mainstream transportation option.

One practical solution has been the hybrid, which backs up an electric motor with a small internal combustion engine. Still, the all-electric vehicle will have more appeal if it can become more practical. EVs are slowly emerging as a viable alternative to conventional gasoline vehicles. New battery technology is making the EV more practical, but the real secret to its ultimate success is the charging system. This white paper takes a look at EV charging systems and their design.

Historical background

EVs first appeared in the 19th century. Multiple manufacturers made EVs that were popular because of their quiet operation. However, few had the electrical power at home to recharge the batteries, and the range and speed were limited. Around the same time, practical internal combustion engines appeared along with cheap gasoline, giving EVs considerable competition. Despite their loud demeanor and the need for a hand-cranked start, these cars outsold EVs, with the launch of the highly affordable Ford Model T in the early 20th century leading to their initial demise.

Over the years, interest in EVs came and went. The early 1970s saw attempts to reintroduce EVs when oil prices rose and gasoline shortages occurred. Growing interest in climate change, clean air initiatives and emissions regulation spurred EV research in the early 1990s. Around the same time, GM developed the EV1 – but discontinued it for lack of interest. Then along came the hybrids, including the Toyota Prius, in the early 2000s. EVs have only become more prevalent as battery technology has improved.

The battery challenge

The earliest EVs used lead-acid batteries, as did some EV and hybrid prototypes, because of their low cost and wide availability. Size and weight were limiting factors, however. Because lead-acid batteries have a low energy per weight and volume rating (batteries are rated by their specific density or energy density, stated in watt hours per kilogram [Wh/kg]), early hybrids and EVs used smaller and lighter nickel metal hydride batteries. Then the lithium-ion battery came along, and rapid R&D produced the highest energy-density battery available. After quick adoption in EVs and hybrids, lithium-ion and its varieties are now the batteries of choice for EVs going forward.

The pros and cons of EVs

The primary advantage of EVs is that they produce zero emissions. Their carbon footprint is minimal and related to the energy used in recharging from the power grid, which may use carbon-based fuel (however, much more efficiently than a gas powered vehicle). EVs are also silent in operation –

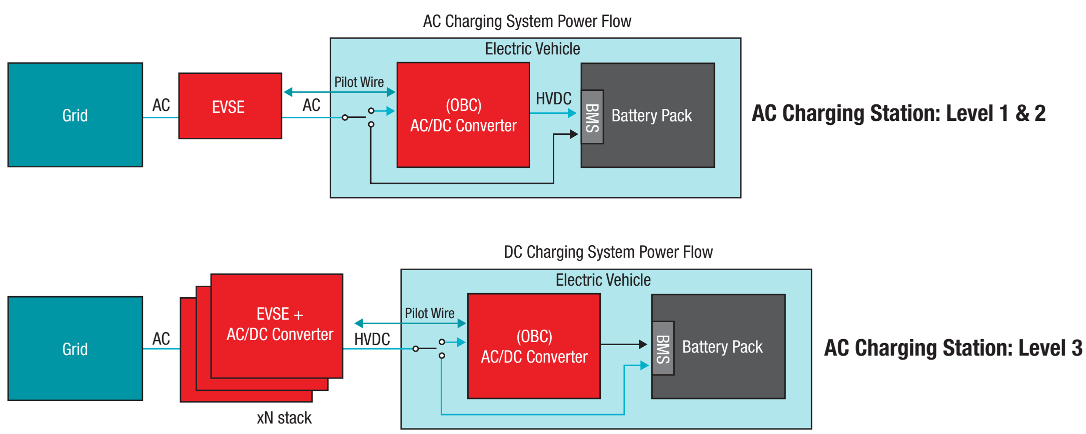
and fast. Thanks to powerful three-phase four-pole AC induction motors or permanent-magnet AC synchronous electric motors, they offer exceptional low-end torque and acceleration. These desirable features tempt buyers, but the disadvantages are what have kept EV annual sales to less than 1 percent.

The downsides of EVs include price, range, and battery-charging issues. Prices are still high because of the high battery cost and small production volumes. Range is one of the greatest limitations due to battery capacity. Early EVs had a range of only 50 to 100 miles on a full battery charge. Today, new batteries have improved the range to over 200 miles on a full charge. That may be OK for local commuting and short shopping trips, but it is insufficient for longer-range travel and routine trips in rural areas. People are afraid of running out of power with no charging stations nearby.

Lack of sufficient charging stations is another disadvantage. Range would not be as much of a problem if more closely spaced charging stations were available. While the number of charging points is gradually increasing (the U.S. Department of Energy estimates just over 16,000 charging stations in the United States[1]), a larger national network is needed to compete with the hundred thousand-plus gasoline stations.

On top of that is the limitation of long charging times. It takes eight to 17 hours for a full-from-scratch recharge when charging from an AC outlet at a home or public charging station. Partial recharges are only several hours long. Yet that is still unreasonable when consumers have become accustomed to refilling their automobiles with gasoline in only minutes.

Thankfully, new semiconductor reference designs are helping manufacturers create charging stations that deliver faster charging times than ever before.



EVSE type	Power supply	Charger power	Charging time* (approx.) for a 24 kWH battery
AC charging station: L1 residential	120/230V AC & 12 A to 16 A (single phase)	~1.44 kW to ~1.92 kW	~17 hours
AC charging station: L2 commercial	208 ~ 240 VAC & 15 A ~ 80 A (single/split phase)	~ 3.1 kW to ~19.2 kW	~8 hours
DC Ccharging station: L3 fast chargers	300 to 600 VDC & (max 400 A) (poly phase)	from 120 kW up to 240 kW	~ 30 minutes

***Figure 1**. The organization of EVSE levels 1, 2 and 3.*

Charging systems overview

EV battery-charging units are also known by the term electric vehicle service equipment (EVSE). There are three types, as shown in **Figure 1**. Levels 1 and 2 as established by Society of Automotive Engineers (SAE) standard, supply power to the on-board charger built into the vehicle. Level 3 uses a power-conversion stage built within an external charger and bypasses the on-board charger on the EV. A level 1 EVSE design uses commonly available 120 VAC power line and draws current in the 12 to 16 A range. It takes 12 to 17 hours to fully charge a 24 kWH battery.

EVSE at level 2 uses a standard 240 VAC service to power a more robust vehicle charger. It draws anywhere from 15 to 80 A to completely charge a 24 kWH battery in about eight hours. EVSE at level 3 uses an external charger that supplies high-voltage (300 V-750 V) DC at up to 400 A directly to the vehicle's battery. The charging time for a 24 kWH battery is less than 30 minutes. Home chargers are level 1 or 2, while public charging stations are level 2 or 3.

Special connectors connect the vehicle to the AC or DC source. The most common is the J1772, an SAE standard. It has five pins: three for the split-phase 240 VAC, one for proximity signal detection, and a pilot signal. The proximity signal disables the vehicle while the charger is connected. The pilot signal is a two-way communications interface and protocol that negotiates between the battery status and energy available.

The most common high-voltage DC connector is the Charge de Move (CHAdeMO), which includes a pin for Controller Area Network (CAN) bus communications. Another, the Combined Charging System connector, adds two pins for the high-voltage DC to the five pins compatible on the J1772. Other, similar connectors are also available in Europe.

EVSE design

Figure 2 shows the main components of EVSE for levels 1 or 2. The split phase 120/240 VAC power line is first distributed to the power supply for the monitoring, control and communications circuits. The AC line then encounters sensor circuitry that monitors and filters the current and voltages in the system. The AC is applied to high-current contacts on a relay before connecting to the pins on the J1772 connector. A microcontroller (MCU) such as the TI MSP430™ MCU manages the monitoring, control and communications circuits. MSP430 with capacitive touch sensing peripheral such as CapTIvate™ technology can also control the

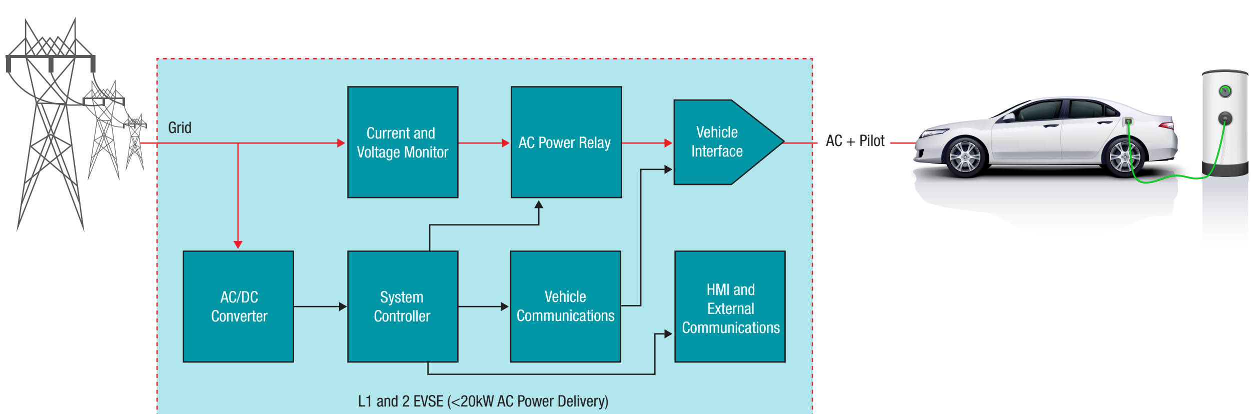


***Figure 2**. Typical configuration of EVSE levels 1 and 2.*

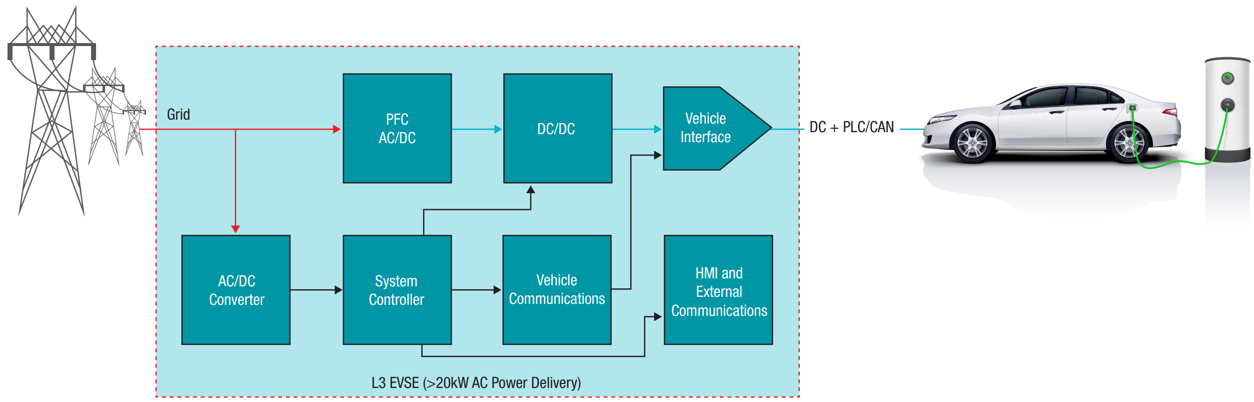


Figure 3*. Typical configuration of EVSE levels 3.*

common user input/output (I/O) links to a human machine interface (HMI) with a liquid crystal display (LCD) touch screen and controls. One or more communications ports complete the EVSE.

Figure 3 shows the main components of a DC EVSE for level 3. The three-phase AC is conditioned by a power-factor-correction (PFC) circuit. The AC is rectified by active metal-oxide semiconductor field-effect transistor (MOSFET) rectifiers into a high-voltage DC of about 400 V. This voltage passes to a DC/DC converter made up of power FETs or insulated gate bipolar transistors (IGBTs) that generate the correct DC level of about 400 VDC for charging the battery. One or more MCUs (like TI's C2000™ MCU series) manage the monitoring and control, AC/DC and DC/DC power-conversion processes. The ARM® based Sitara™ processor can provide advanced HMI and point-of-sale and billing capabilities in conjunction with MSP microcontrollers with capacitive touch-sensing technology.
Note the power line communication (PLC) and CAN interfaces so the EVSE has a high-speed communication link to the vehicle.

Communications interfaces

All EVSE stations use some form of communications to assist in the charging process. In EVSE at levels 1 and 2, the pilot signal port lets the AC source talk to the vehicle, its internal charger and its battery. The pilot port uses a simple ±12 V pulse-width-modulated (PWM) 1 kHz signal to indicate the charge state and current available from the AC source. Incorporating Wi-Fi® into some systems helps manage the charging process from any Wi-Fi-enabled device, like a smartphone or tablet. Using an appropriate app, consumers can even locate or schedule time at public charging stations.

The Near Field Communications (NFC) protocol is also used in public charging stations for user authorization and payment. NFC uses a modulated 13.56 MHz signal to transmit and receive low-speed data over short distances. NFC is now available in most modern smartphones.

EVSE level 3 stations use either the CAN bus or PLC protocol. Some systems also use the RS-485 interface to communicate with an external system at a public charging station.

Design resources

Texas Instruments offers a wide range of components and reference designs to speed up and simplify EVSE design:

- Level 1&2 Electric Vehicle Service Equipment Reference Design – This reference design shows how to design and build J1772-compliant EVSE for levels 1 and 2. This design is based on TI's MSP430 MCU and a variety of power integrated circuits (ICs).
- Wi-Fi Enabled Level 1 and Level 2 Electric Vehicle Service Equipment Reference Design – This is a version of the level 1 and 2 reference design that incorporates the SimpleLink™ Wi-Fi CC3100 wireless network processor to implement Wi-Fi and permits remote power monitoring and control.
- NFC Authentication for an EV Charging Station (Pile) Reference Design – This reference design shows how to incorporate NFC authentication capability into EVSE at levels 1 or 2. It features the MSP430 MCU and TRF7970A NFC transceiver.
- Vienna Rectifier-Based Three Phase Power Factor Correction Reference Design – This reference design shows how to implement Vienna rectifier power topology that is popular in high power three phase power factor (AC-DC) applications such as EVSE at Level 3.
- HV Resonant LLC Developer's Kit – This developer's kit shows the design of an LLC resonant DC/DC converter applicable to level 3 designs.
- Two-Phase Interleaved Power Factor Correction Converter with Power Metering – This is a design kit for a PFC converter useful in level 3 designs.
- Capacitive Touchscreen Display Reference Design – This is a touchscreen reference design using TI Sitara AM437x processors.

More reference designs, development kits and resources are available at Grid Infrastructure portal on TI.com

References

1. U.S. Department of Energy, Alternative Fuels Data Center, retrieved 19 September 2017.

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