White Paper

Optocouplers Support Safe and Fast DC Charger for Electric Vehicles

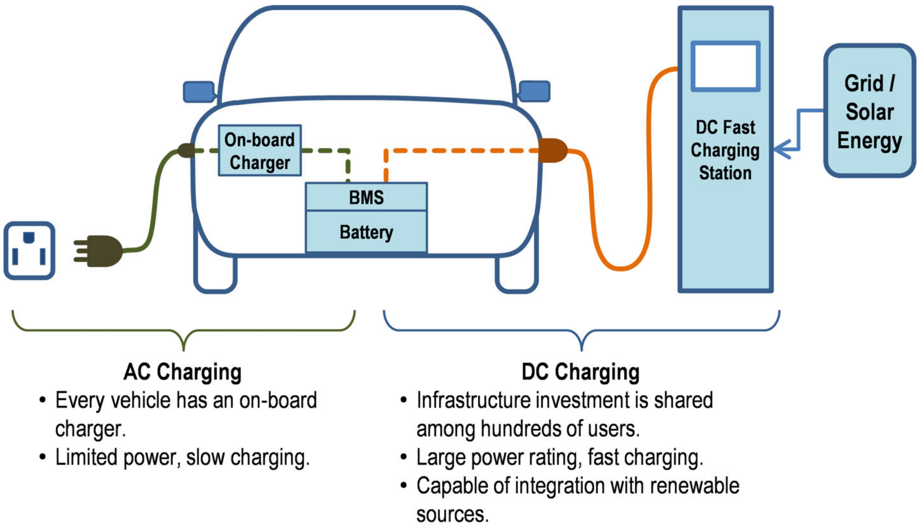
Abstract

Rapid growth of electric vehicle (EV) fleet drives strong demand for charging infrastructure to extend EVs' travel range. DC fast-charging stations can shorten the charging time from hours to minutes. In designing DC fast-charging stations, one of key aspects is the electrical safety, which can be addressed by using optocouplers.

Introduction

The grid transmits power in AC form, and energy stored in the on-board battery is in DC; therefore, a charger is required to perform the conversion job. Depending on whether the charger is installed inside of the vehicle, chargers can be categorized into an on-board charger (OBC) and an off-board charging station. An OBC accepts the AC power source from mains supply and converts it to DC to charge the battery, which is slow due to the limited power rating of the charger. DC charging is often used in off-board charging stations. It supplies regulated DC power directly to the batteries inside the vehicle. As the DC-charging equipment is installed at fixed locations with little constraint of size, its power rating can be as high as several hundreds of kilowatts. The DC fast-charging method shortens the charging time from hours to minutes [1], [2]. Figure 1 illustrates the AC and DC charging methods. DC fast charging is a key instrument in the successful roll-out of electric vehicles to reduce or eliminate range anxiety.

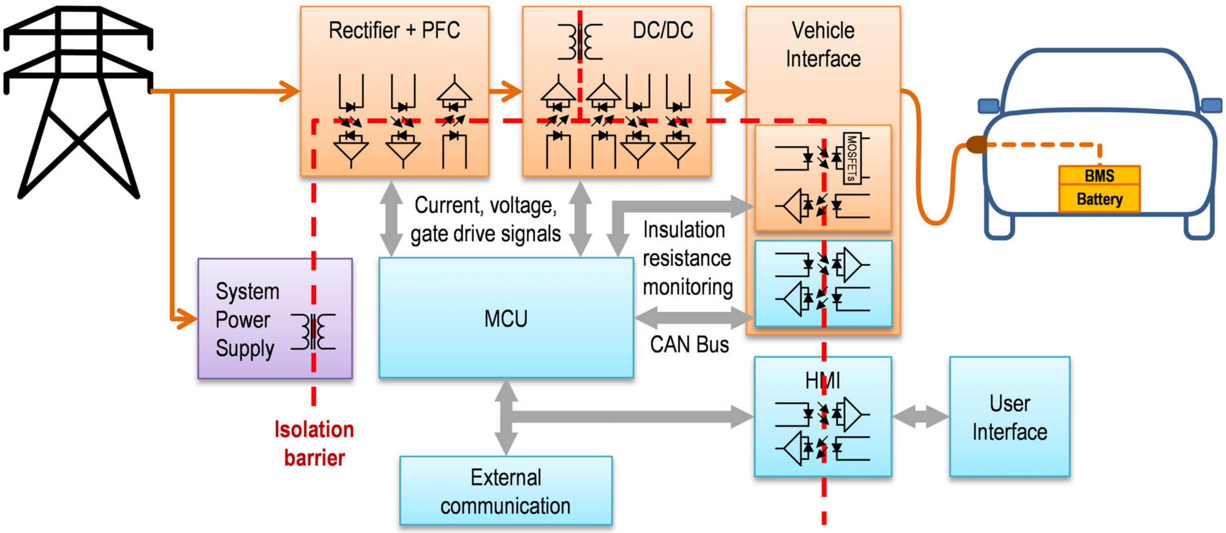
Figure 1: AC Charging and DC Charging [3, p. 6].



Designing a Charging Station with Safety Isolation

A DC fast-charging station typically includes functional blocks, such as an AC-to-DC rectifier, a power factor correction (PFC) stage, and DC-to-DC conversion to regulate the voltage level suitable to charge the battery in the vehicle. Energy delivery and charger-vehicle communication are done through the charger coupler interface. Figure 2 shows a simplified block diagram of a DC-charging station design. In this diagram, a safety isolation barrier is designed in the functional blocks, which ensures that the design safety complies with regulatory standards.

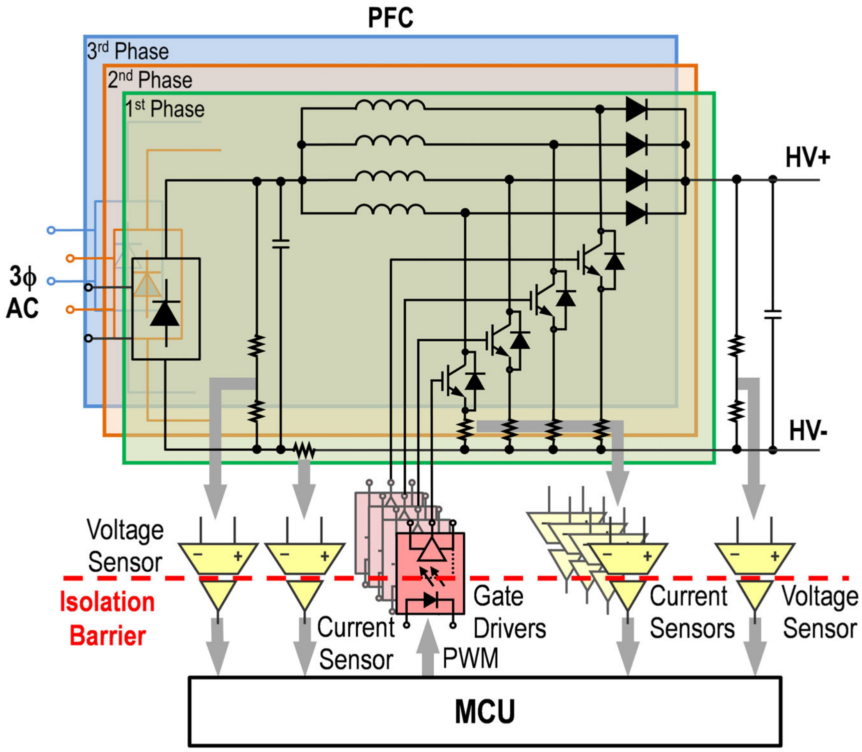
Figure 2: A Block Diagram of an EV Charging Station



Using Optocouplers in the PFC Stage

A power factor correction (PFC) stage transforms the input current close to a sinusoidal waveform, which is in phase with the grid voltage. This transformation reduces the harmonics injected to the power grid and improves the power factor to comply with various standards. The PFC stage also generates a regulated DC output voltage to supply the downstream DC-DC converter. Figure 3 shows an example of interleaved PFC stage.

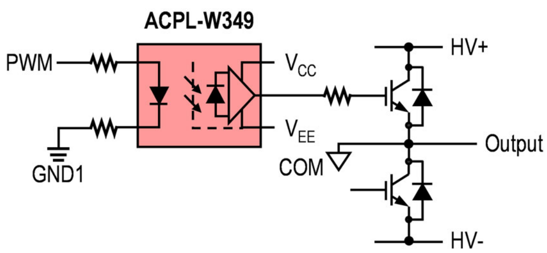
Figure 3: Using Gate Drive, Current, and Voltage Sense Optocouplers in the PFC Stage



In this stage, the MCU (microcontroller unit) alters the PWM (pulse-width modulation) signals to switch the power MOSFETs or IGBTs on and off and alters the duration of each status according to the control algorithm. Gate drivers amplify the PWM signals with larger voltage and current magnitudes to drive the power-switching devices at the desired frequency.

Figure 4 shows an example gate drive circuit. In this circuit, the ACPL-W349 features 2.5A output current, rail-to-rail output voltage range, and a very short (55 ns) short propagation delay time. Packaged in an SSO-6 small surface-mount device, this part has an isolation voltage rating of 5000 Vrms for 1 minute per the UL1577 standard, and 1140 Vpeak per the IEC/EN/DIN EN 60747-5-5 standard. These standard approvals ensure the safety of the controller and the user side.

Figure 4: A Simplified Gate Drive Optocoupler Application Circuit

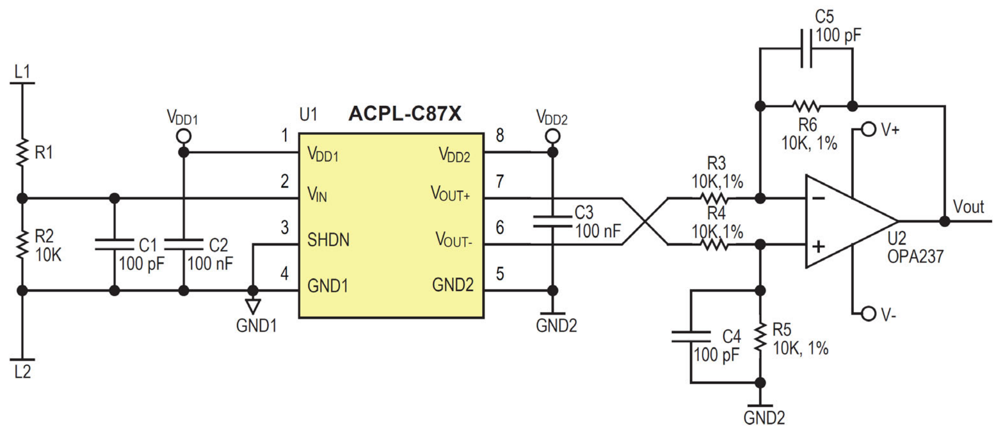


In the PFC stage, various voltage and current signals are required to implement the control algorithm. These include the rectified input voltage, the current of each of the interleaved phases, the total current, and the DC bus capacitor voltage.

The typical method of measuring high voltage is to use a resistive potential divider to step down the voltage to a suitable level so that a linear sensing chip can measure it and send it to the MCU. A current-sensing circuit often uses a precision shunt resistor to convert the current to a small voltage, which is sent to the MCU using some signal-conditioning devices. To transmit the signals accurately from high-voltage areas, such as the PFC and DC-DC converter stages to the low voltage MCU side, isolation amplifiers, such as the ACPL-C87X series and ACPL-C79X series, are available to carry out the voltage and current-sensing functions [4], [5].

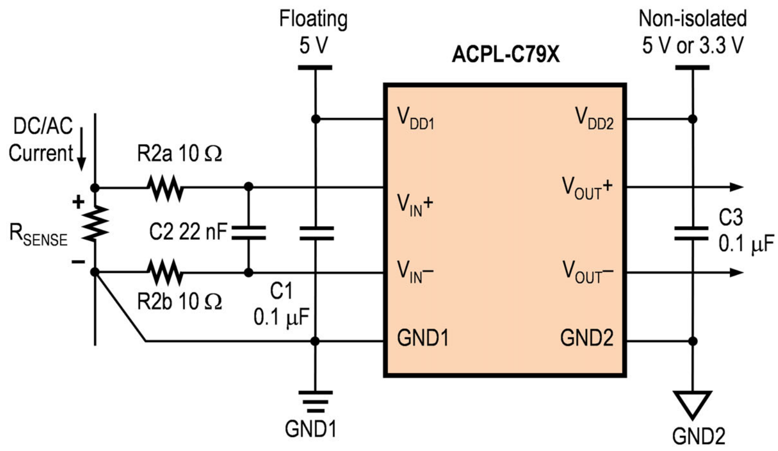
Using the ACPL-C87X isolated voltage sensor is straightforward as shown in Figure 5. Given that the ACPL-C87X's nominal input voltage for V_{IN} is 2V, choose resistor R1 according to $R1 = (V_{L1} - V_{IN}) / V_{IN} \times R2$. The down-scaled input voltage is filtered by the anti-aliasing filter formed by R2 and C1 and then sensed by the ACPL-C87X. The isolated differential output voltage ($V_{OUT+} - V_{OUT-}$) is converted to a single-ended signal V_{OUT} using a post amplifier U2. V_{OUT} is linearly proportional to the line voltage on the high voltage side and can be safely connected to the system microcontroller. With the ACPL-C87X typical gain of 1, the overall transfer function is $V_{OUT} = V_{L1} / (R1/R2 + 1)$ [4].

Figure 5: High Voltage Measurement with Conversion to an Isolated Ground Referenced Output



Using an isolation amplifier to sense current can be as simple as connecting a shunt resistor to the input and getting the differential output across the isolation barrier, as shown in Figure 6. By choosing an appropriate shunt resistor, a wide range of current, from less than 1A to more than 100A, can be measured. In operation, currents flow through the shunt resistor, and the resulting analog voltage drop is sensed by the ACPL-C79X. A differential output voltage is created on the other side of the optical isolation barrier. This differential output voltage is proportional to the current amplitude and can be converted to a single-ended signal using an op-amp, such as the post amplifier shown in Figure 5, or sent to the controller's analog-to-digital converter (ADC) directly [5].

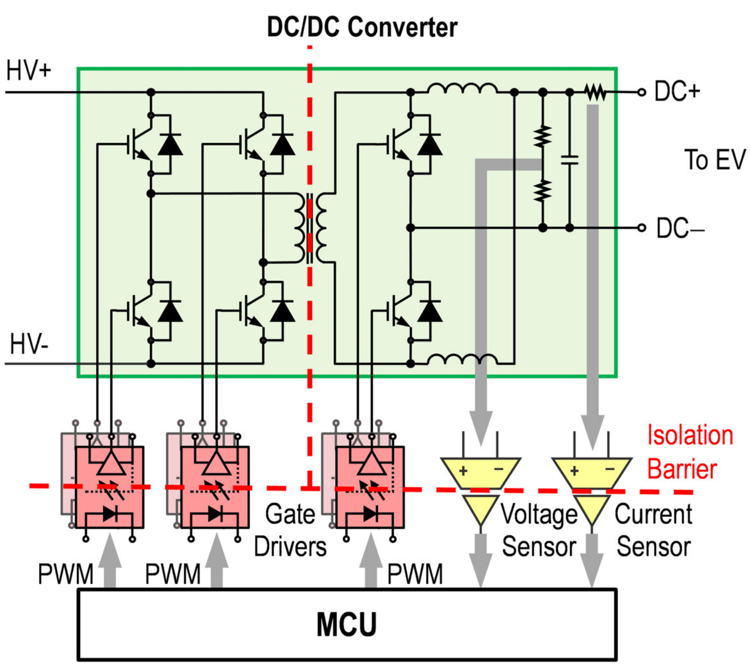
Figure 6: Typical Current Sensing Application Circuit



Using Optocouplers in a DC/DC Converter

As shown in Figure 7, a DC/DC converter stage follows the PFC stage, providing stable DC energy to be transferred directly to the battery. Output voltage and current must be measured and fed back to the MCU for calculation, which adjusts the PWM signals. These PWM signals then control gate drive optocouplers to drive IGBTs or MOSFETs. In this stage, a galvanic isolation barrier is observed along the power transformer and the gate drive, voltage sense, and current sense optocouplers. See Figure 4, Figure 5, and Figure 6 for gate drive, voltage sense, and current sense circuits.

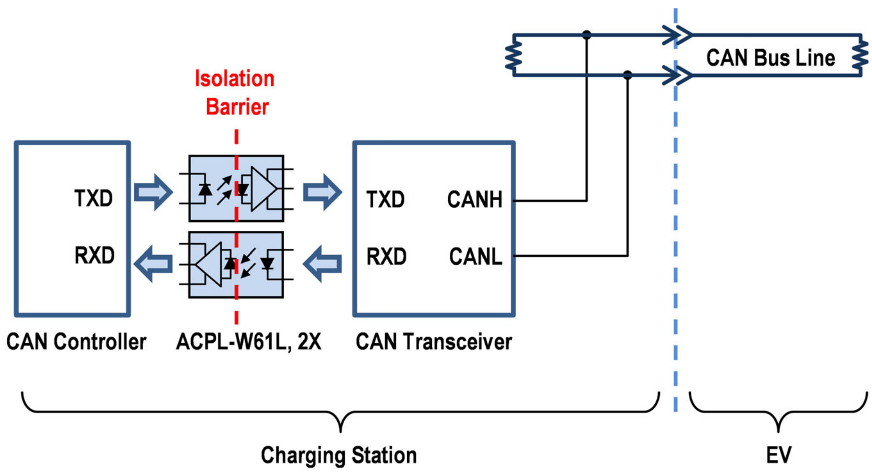
Figure 7: A Simplified DC/DC Converter



Using Optocouplers in a Charger-Vehicle Interface

An advanced control scheme is necessary to implement a charging-control protocol between the charging station and the EV. The most popular plug standard CHAdeMO (based on EV sales with fast charging type) [6] chooses the CAN (Controller Area Network) for fast charging, recognizing its high communication reliability. The CHAdeMO standard provides a pair of CAN bus lines connecting the charger side and the vehicle side at the coupler interface. The coupler pins 8 and 9 are assigned as CAN-H and CAN-L [7, p. “Technological details”], respectively, to which a CAN transceiver can be connected. Adding optical isolation between the CAN transceiver and the CAN controller significantly improves system safety because optocouplers provide a safety barrier that prevents any damage from cascading to the system MCU. This arrangement also enables more reliable data communication in extremely noisy environments, such as high-voltage battery-charging systems. Figure 8 shows how to use optocouplers to implement isolated CAN bus digital communication for fast-charging station designs. A similar circuit is applicable for the vehicle side, where automotive-grade parts are required.

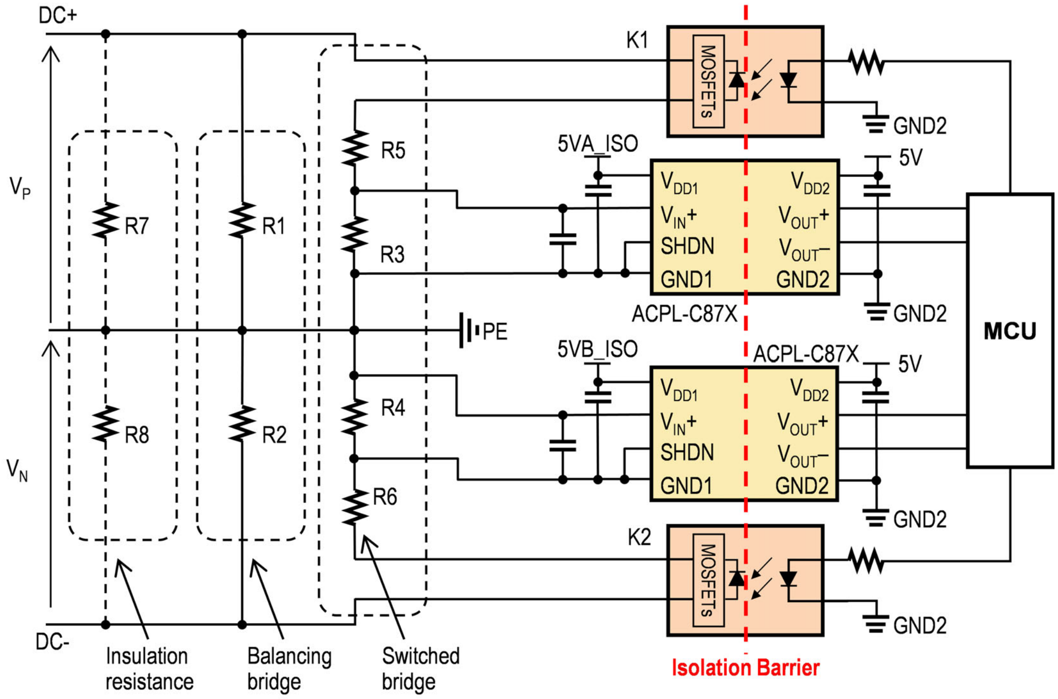
Figure 8: Isolated CAN Bus Digital Communication



In the example circuit shown in Figure 8, a pair of 10-MBd fast ACPL-W61L optocouplers is used for data transmit and receive. This product requires a very low 1.6-mA LED current to work and is delivered in an SSO-6 package that is less than half of the size of a traditional DIP-8 package. Although in small package, the ACPL-W61L can withstand a high voltage of 5000 Vrms for 1 minute, per UL1577 rating. Designed to transmit signals in the presence of strong transient noises, this part guarantees common-mode transient immunity of 35 kV/µs [8]. In case of different design needs, other optocouplers can also be used in place of the ACPL-W61L. These include the 5-MBd-rated ACPL-W21L [9] and the 25-MBb dual-channel bidirectional ACSL-7210 [10].

As one of the safety measures, an insulation resistance monitoring function is required in the EV charging station [11]. One of the possible implementations is shown in Figure 9. In this circuit, isolation amplifier ACPL-C87X measures the voltage signal at its input and sends the output to the MCU. The ASSR-601J consists of an LED input side and two discrete high-voltage MOSFETs at the output side. In application, the two source nodes of the MOSFETs can be used as two contact points of a switch. They can withstand a breakdown voltage of above 1500V when in OFF mode. Both the ACPL-C87X and ASSR-601J use optical coupling technology to provide galvanic isolation while sending signals across the isolation barrier, which is certified by IEC 60747-5-5 with a working voltage of 1414 Vpeak [12].

Figure 9: An Example of Insulation Resistance Monitoring Circuit



Conclusion

EV charging infrastructure is key to enabling wide EV adoption. In an EV-charging station, especially DC fast-charging, complex power supply systems are used to deliver huge amounts of energy to the battery in the vehicle within a short period of time. It can be very challenging to design an efficient DC fast charger while complying with safety-isolation requirements. Optocouplers, such as the gate drivers, voltage sensors, current sensors, and digital optocouplers, deliver both safety isolation and respective electrical functions in a single package, helping realize highly efficient systems.

References

1. Tesla Motors, “Superchargers,” [Online]. Available: http://www.teslamotors.com/supercharger.
2. SAE International, “SAE Charging Configurations and Ratings Terminology,” ver. 100312, 2012.
3. M. Langezaal and C. Bouman, “Towards Winning Business Models for the EV-Charging Industry.” ABB White Paper 4EVC200801-AREN, 2012.
4. Broadcom, “ACPL-C87B/C87A/C870 Precision Optically Isolated Voltage Sensor Data Sheet,” AV02-3563EN, 2013.
5. Broadcom, “ACPL-C79B/C79A/C790 Precision Miniature Isolation Amplifiers Data Sheet,” AV02-2460EN, 2014.
6. B. Scott, “Electric Vehicle Charging Infrastructure: 2015 Update.” *IHS Automotive Tech Report*, August, 2015.
7. CHAdeMO Association, [Online]. Available: www.chademo.com.
8. Broadcom, “ACPL-W61L Ultra Low Power 10 MBd Digital CMOS Optocouplers Data Sheet,” AV02-2150EN, 2012.
9. Broadcom, “ACPL-W21L Low Power 5 MBd Digital CMOS Optocoupler Data Sheet,” AV02-3462EN, 2012.

10. Broadcom, "ACSL-7210 Dual-Channel (Bidirectional) 25 MBd CMOS Buffered Input Digital Optocoupler Data Sheet," AV02-4235EN, 2013.
11. *GB/T 18487.1-2015, Electric Vehicle Conductive Charging System – Part 1: General Requirements*, 2015.
12. Broadcom, "ASSR-601J 1500V High Voltage Photo-MOSFET Data Sheet," 2017.

BROADCOM®