2 Control

The EV Charging Infrastructure Designbook: Volume 2

Control



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The EV Charging Infrastructure Designbook:

Control

This is the second in a series of guides for designers of fixed AC and DC EV charging stations, where we consider control functionality necessary and its implementation. ‘Control’ includes the circuitry required to sense and monitor the charging operation and drive the various power conversion stages appropriately for safe, accurate and efficient delivery of power to the battery.

Also considered is the remote control and monitoring of the charger system, whether by the utility company or the vehicle driver, to enable secure charge scheduling, V2G and V2B operation, and billing. A further guide will address the detail of the connectivity functions required.

In the first of this series of design guides for EV chargers, we considered power conversion stages, along with some of the associated energy monitoring and protection features. In this design guide, we look at the control functions and hardware necessary to achieve safe and efficient power connection/conversion, along with the necessary interfaces to the outside world for monitoring, convenience features and billing.

Connecting safely

Proximity detection

At the highest level, the connection between charger or Electric Vehicle Source Equipment (EVSE) and vehicle is by a cable and connector combination. In the power stage design guide, the different connector types in common use globally were identified as Type 1, Type 2, Combo 1, Combo 2, GB/T and CHAdeMO. As well as power pins, each connector type features signal connections for control and communication. For the connectors popular outside Japan and China, with an AC power source, the PP, or 'Proximity Pilot' pin signals to the power source or EV what the cable assembly current rating is by a resistor in the connector to ground (***Table 1***).

If the current is exceeded, the power line can be disconnected by the source, and/or the EV can know not to take or source more current than the cable is capable of. The pin also serves to indicate to the source that voltage can be applied, as it physically mates last after a secure and sealed connection is made for the power pins. The coding resistor is fitted in a free connector, mating with the EV, and in a free connector mating with the charger, depending on configuration, so the PP function is achieved in connectors and is not a wire in the cable. Standard IEC 61851-1 gives a full description of the functionality required. The standard also indicates that the proximity function could be achieved with a push-button/latch on the connector, which needs to be depressed before mechanical mating or de-mating can occur. Pressing the button also has the effect of activating the PP signal, so that power is removed.

Cable assembly current capability A	Nominal connector resistor Tolerance +/-3% Ohms	Range of resistance for interpretation by the EV supply equiment Ohms
	Error condition	> 4,500
13	1,500	1,100 - 2,450
20	680	400 - 936
32	220	164 - 308
63 (3-phase) 70 (1-Phase)	100	80 - 140
	Error condition	< 60

Table 1: *PP line resistance signifies cable current capability*

The Control Pilot line

The CP or 'Control Pilot' connection is a wire in the cable and in its simplest implementation, passes voltage from the EVSE to the EV through a resistor, so that when the EV is connected and a further resistor is inserted in line by the EV, the CP line voltage drops by a potential divider effect. This signals that there is a through-connection between the EVSE and EV, which then switches in another resistor to drop the voltage further, to indicate it is ready to accept a charge. The voltage is +12V open circuit and when connection is made, it drops to 9V. When the EV is ready to receive energy, it connects another resistor, dropping the voltage further to 6V. After this successful 'handshaking', the CP line then alternates between -12V and a positive voltage depending on state, at nominal 1000Hz with the width of the pulse indicating the current capability of the source (***Table 2***).

The specification for the CP line also allows for comprehensive bi-directional digital communication between the EVSE and EV. This is indicated by the 1000Hz signal remaining at 5% pulse width, under which condition the system expects to see a high-frequency, lower-level signal superimposed at greater than 148kHz. The communication protocol and implementation are described in standards ISO/IEC 15118 and ISO 17987-2 for a 'Local Interconnect Network' (LIN) for road vehicles. Transformers are used to couple the high frequency onto the CP line at each end and are available from companies such as Bourns and KEMET as standard or custom parts. EV charging connectors are available from suppliers such as Amphenol.

Current (A)	DUTY CYCLE
5	8,30%
15	25%
30	50%
40	66,6%
65	90%
80	96%

Table 2: *Control Pilot signal duty cycle signifies EVSE current rating*

Control in the AC wall box

A wall box EV charger with AC output can be of varying complexity, depending on whether it is for household or commercial use. The minimum function required is to measure current and voltage to evaluate energy delivered and to shut down the output under fault conditions via in-line relays. The Proximity Pilot and Control Pilot functions are also necessary. The block diagram given in ***Figure 1*** is typical of a fully-featured single-phase unit with wireless interfaces for monitoring and control via an app or in-car connectivity and perhaps NFC functionality for user authentication and billing. The diagram also shows wired communication possibilities through the Control Pilot connection already described. Current sensing would typically be implemented with transformers, generating isolated, low-level signals that can be directly interfaced to a microcontroller. However, resistive shunt sensing for line current is possible, for guaranteed linearity and no saturation effect, in which case an isolation amplifier might be used such as the ACNT-H790 from Broadcom, providing an output which can directly interface with a differential or single-ended ADC. The part achieves an accuracy of better than +/-1% across a wide temperature range to 105°C with a linearity of 0.05%.

As well as a continuous check on protective earth continuity, Ground Fault Current Indication (GFCI) is necessary for safety, and a transformer is an effective solution. A GFCI controller can be employed to program trip levels and times, and a product such as the NCS37015 from Onsemi features a latching output and a self-test function, as required by UL943, on startup and every subsequent 17 minutes.

Drives to the relays can be given some intelligence to ensure secure operation and minimum dissipation. The HV9901NG-G relay driver from Microchip for example, features programmable pull-in current, pull-in time and hold current, providing PWM output to an external MOSFET relay driver.

A microcontroller handles the processing of measured parameters and interfaces to wireless and wired communications modules, discussed in a later design guide on connectivity. The display can also be driven from the microcontroller or through its own dedicated device. STMicroelectronics STM8 8-bit microcontrollers could be suitable for simpler AC wall box applications or alternatively the 32-bit STM32 range for a feature-rich commercial wall box.

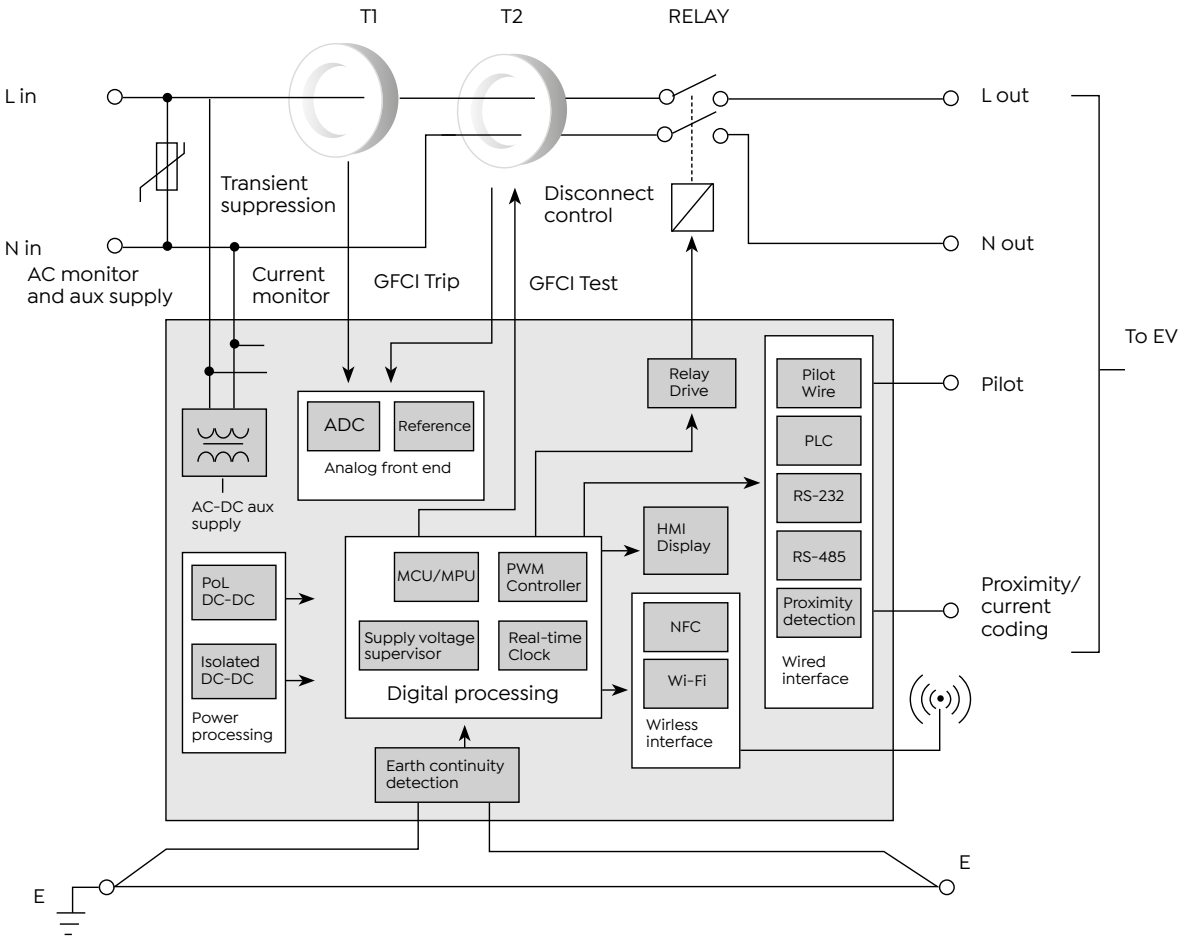


Figure 1: *Control in a fully-featured AC wall box*

DC fast charger control functions

Communication between charger and EV

Standard IEC 61851-23 defines the requirements for DC or 'Level 4' chargers and in the Combined Charging System (CCS) standard connections, a high level of digital communication is necessary via IP-based Power Line Communications (PLC) over the Control Pilot line. CAN is used for this communication in the Japanese DC GB/T and Chinese CHAdeMO connection standards, through dedicated pins. This level of communication is necessary as the EVSE has a direct DC connection to the EV battery, so it must respond to current demand from the EV and be made aware of the rated battery voltage, maximum charge current and the integrity of the connections and equipment. Standard IEC 61851-24 describes the digital communication requirements, including exchange of:

- Current value requested by EV
- Voltage value requested by EV
- Maximum rated voltage value of DC EV charging station
- Maximum rated current value of DC EV charging station
- Communication protocol/software version of charging system
- Maximum voltage limit value of EV
- Result of insulation test
- Result of short circuit test
- Charge stop command by user
- Real-time available load current for demand management (optional)
- Loss of communication information
- Zero current confirmed (to allow connector unlocking)
- Contact welding detection information

Powerline transformers are used to superimpose the data on the CP line, as described in the section on AC wall boxes, while CAN transceivers from suppliers such as Microchip, NXP or ROHM could be used on the DC GB/T and CHAdeMO connections.

Another standard that applies is ISO 15118 'Road vehicles – Vehicle to Grid Communications Interface' which builds and expands on IEC 61851 and is relevant to chargers that use powerline communications on the CP line. ISO 15118 implements the following features through defined protocols:

- Security concept including encryption, signing, key management, etc.
- Robust PLC-based communications
- Automatic address assigning and association
- IPv6-based communications
- Compressed XML messages
- Client-server approach
- Safety concept including cable check, welding detection, etc.
- Extension concept for added-value services

The standard includes a feature called 'Plug and Charge' where authentication, billing and battery charge negotiation is achieved by simply plugging-in the EV to the charger, without the need for an app or card. The process is encrypted and secure. Germany however, requires by law that access through a debit/credit card is still implemented for new charger installations, to ensure wider inclusivity.

Other features of the ISO 15118 protocols include ability to communicate to a local utility supply controller where multiple EVs are charged together, perhaps at a service station. Energy can be apportioned between the EVs, to ensure that demand is sufficiently met without overloading the local grid.

Charging regime

DC chargers provide energy at different levels, currently up to around 350kW. At all rates, but particularly at the highest, the profile of voltage and current must be carefully controlled, monitoring battery temperature, to ensure safest and quickest charging. Demand is set by the on-board battery management system and relayed to the charger along the communication lines described. For a heavily discharged battery and for 'regular' charging, an initial constant current of 0.25C (50A for a 200-Ah battery for example) is allowed until the battery pack voltage rises to the equivalent of about 2.8V per cell. After this, the full charge current is applied until the target voltage is reached, between 4.1V – 4.2V per cell, depending on temperature, representing about 70% of capacity. After this, the charger operates in constant voltage mode and the current slowly drops and is set to terminate at some low value (***Figure 2***). For 'fast' charging, the battery is charged

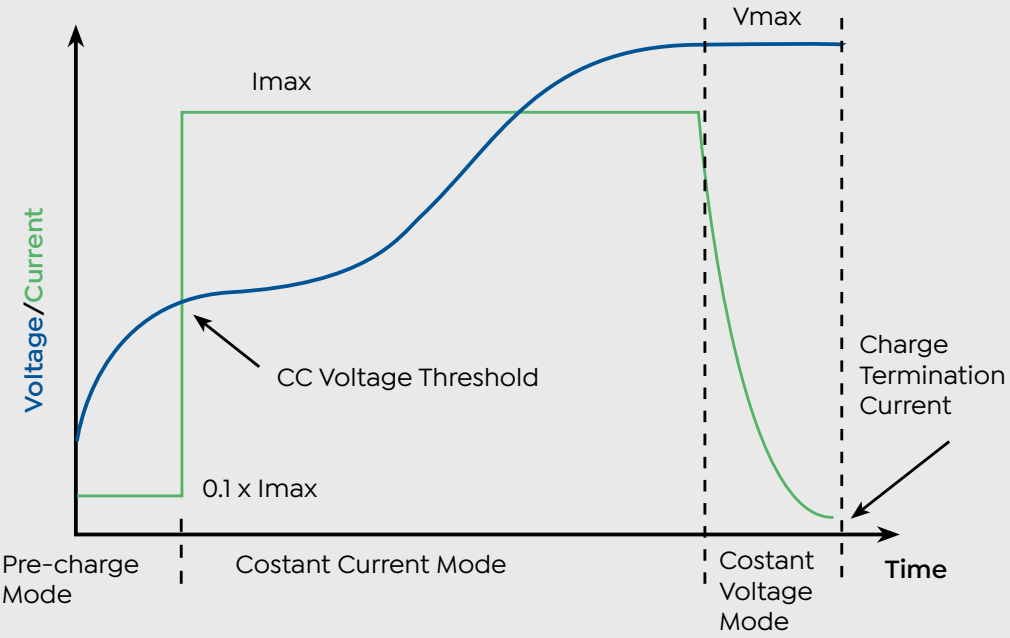


Figure 2: *A lithium-Ion battery charging regime – constant current/voltage*

at a rate of 2C for an initial period of 20 minutes, followed by 1C for 10 minutes, ending with 0.5C for a further 4 minutes. For a 200-Ah battery pack, this means the 80% charge level would be achieved within 34 minutes, equivalent to about 300km range.

Bi-directionality control considerations

Much is made of the possibilities for bi-directional transfer of energy to and from an EV. The rationale is that over 90% of cars are parked and idle at any one time and EVs will have some level of excess charge available. This could be used for balancing the grid, for the benefit of the utility provider, as in 'vehicle to Grid' (V2G), or contributing to a mini- or micro-grid for a dwelling (V2B) or small area, to enable resilience against power outages.

Level 1, 2 and 3 AC charging is not really suitable – although an on-board charger can be bi-directional and supply AC back to the source, this cannot be coupled easily back to the grid for credit as it is not phase-synchronized. It could be used as a local supply to take over with any grid outages, but there would need to be expensive, automated isolation circuitry or 'islanding' protection to ensure that AC does not 'back-feed' into the utility supply, endangering line operators. Some car makes route AC generated by the on-board charger working 'in reverse' to standard domestic power outlets on the vehicle so that appliances or equipment can be plugged directly in. This provides some emergency backup and a convenient power source, for example, when camping. In all cases, the power available is limited by the on-board bi-directional charger which could be less than 2kW.

With DC charging, a fixed, bidirectional AC-DC converter can be arranged to synchronize with the utility supply easily, and with islanding protection, it could have a permanent connection which automatically switches to return energy to the grid in high-demand periods and take energy perhaps overnight, when demand and costs are lower. Some control can be given to the energy provider to schedule charging for grid balancing and this could be achieved over a cellular connection. Otherwise, the user can over-ride the controls and set their own schedule. Alternatively, the battery voltage present at the charger output can also route to a central battery storage as additional capacity in a 'smart home' arrangement, or 'Vehicle to Building' (V2B) where renewable energy also couples in. In this case, the EV charger could also function as the 'grid-tied inverter' that would anyway be needed. Standard ISO 15118 sets a communication protocol for control of bi-directional energy flow.

Bi-directionality is unlikely to feature in 'fast chargers' which are typically located in highway stops, where the users' priority is to obtain extra range as quickly as possible. Communications between EV charger and EV will still interface to a local control hub via perhaps ethernet or wireless, or through a cloud-based service, to identify and limit total site energy requirements, avoid grid overload and provide billing services.

Controlling the DC charger power stages

As described in the first part of this series of design guides, an EV DC charger has two basic power stages, a 'front end' incorporating AC rectification and a DC-DC conversion stage. Both may be bi-directional. A block diagram showing control functions is given in ***Figure 3*** for a typical charger rated at 50kW with three-phase AC input.

Current and voltage sensing

To maintain an accurate charging profile, a commercial DC charger must be suitable for quite precise constant current and voltage operation with accurate sensing of voltage and current. This is anyway required for measuring the total energy supplied and billed to the user. Some power conversion topologies do not suit a wide-ranging output voltage, with the higher efficiency, resonant variants sometimes less suitable. The first design guide on 'EV charger power stages' described some of the conversion topology options and the current sensing techniques – resistive, hall effect and fluxgate sensors.

Gate drives

Power switch gate drives are a requirement for all front-end and DC-DC conversion topologies with the most complex arrangements needing perhaps twenty or even more, half of which would be high-side, that is, driving switch gates that are not referenced to ground. These gate drives mostly require signal and power isolation and will

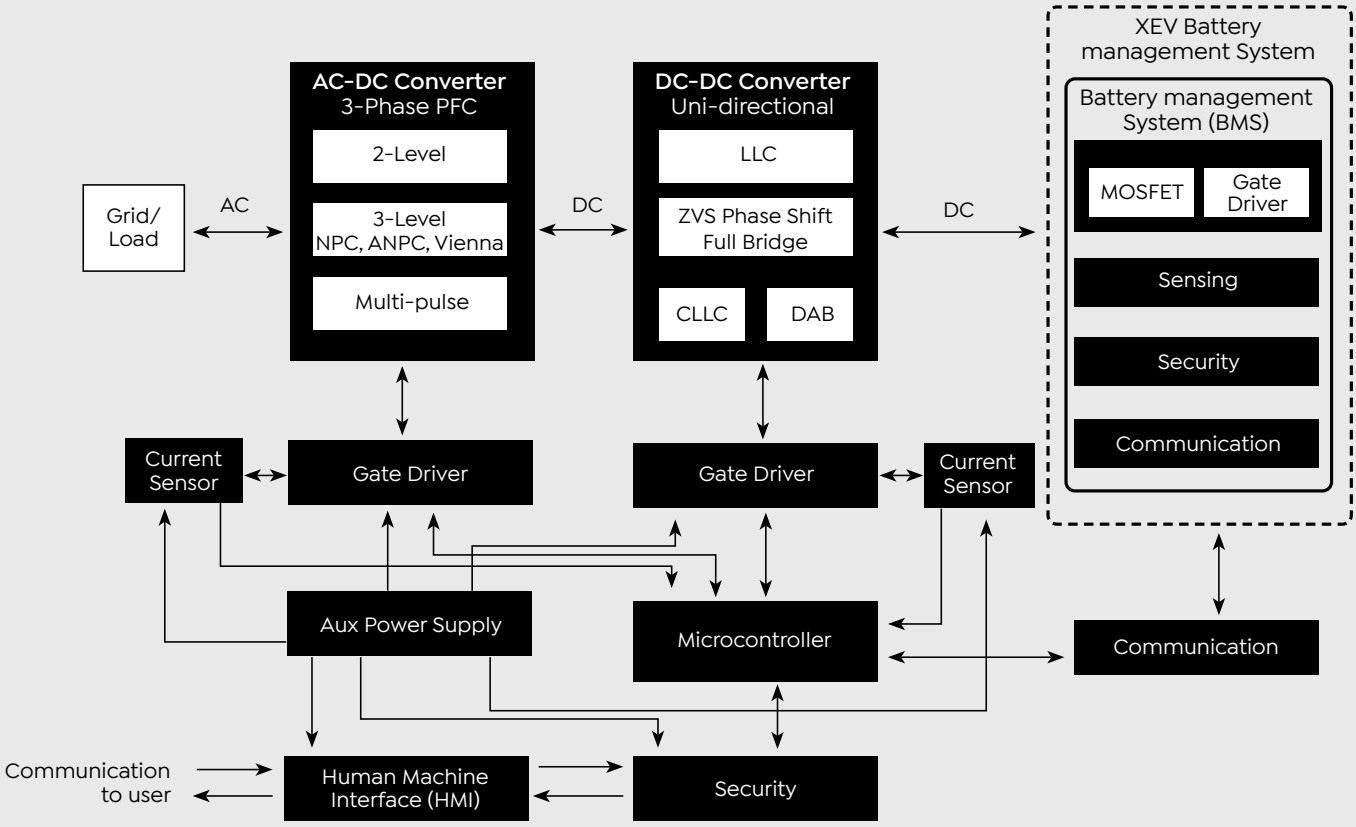


Figure 3: *Control in an EV DC charger*

often include fault monitoring such as under- and over-voltage of the supply rails and de-saturation detection. The efficiency of each power stage depends critically on the gate drive dynamic performance and also voltage levels, the requirements for which vary, depending on the switch technology. IGBTs and silicon MOSFET switches operate with a relatively wide tolerance of gate drive voltages, often 0-12V but sometimes with a negative voltage for the off-drive. Wide band-gap (WBG) Silicon Carbide (SiC) switches have an on-state threshold voltage that is only a few volts, but need around 18V for full saturation, which is relatively close to their absolute maximum voltage of typically 23V. Gallium Nitride (GaN) HEMT cell switches have a recommended on-drive voltage of around 6V but the absolute maximum is only around 7V, so for both wide-band-gap technologies, the gate drive must be carefully designed to avoid overvoltages. Although all technologies are nominally off with a gate voltage of 0V, they can benefit from a negative off-drive voltage. This is to offset the effect of any connection inductance that is common to the power path and gate drive loop, causing voltage transients with drain current steps. These tend to oppose the gate drive voltage, risking 'phantom turn-on', shoot-through and potentially catastrophic damage. There is also a similar danger caused by the 'Miller' effect, the non-linear capacitance from gate to drain of the switch, injecting current into the gate drive circuits with voltage steps on the drain of the switch. Again, a negative off drive of typically a few volts prevents spurious turn-on or off (***Figure 4***).

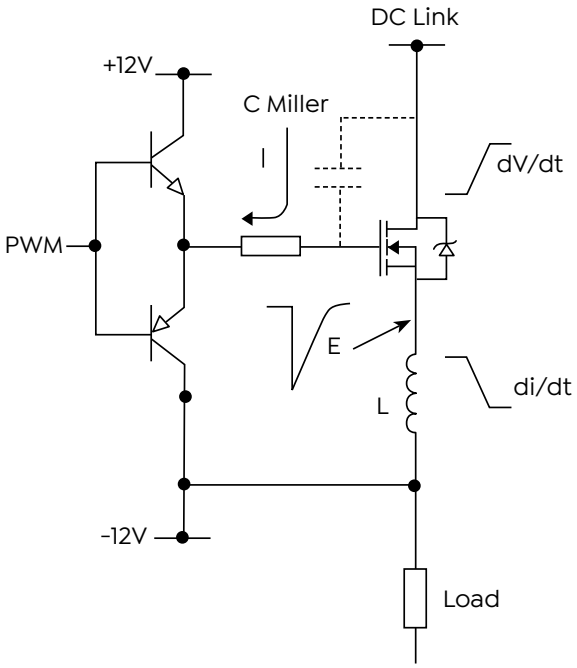


Figure 4: *Power switch gates are often driven negative for the off-state to offset voltage transients from connection inductance and device 'Miller' effect*

Total gate voltage swing is a factor in gate drive power dissipated from the charging and discharging of gate capacitance, so power dissipation increases with a higher negative off-state voltage as well as with frequency. This can cause significant extra power dissipated in the IGBT and Si-MOSFET gate drive circuit. However, WBG devices have very low gate capacitance, so the effect is usually insignificant, despite the often much-higher switching frequency utilized.

As mentioned, high-side gate drives normally have outputs that are isolated. Indeed, their outputs are referenced to a switching node that might be transitioning at 100kV/µs with a wide band-gap device, from zero to the DC-link voltage. This waveform appears across the driver isolation barrier, and produces displacement current through barrier self-capacitance, which finds an indeterminate return route through the control circuitry. This effect can cause EMI and chaotic operation or even damage so must be minimized. Gate driver barrier capacitance is therefore an important parameter and is usually designed to be no more than a few pF. Any local DC-DC converter that provides isolated power to the gate driver must similarly have low isolation capacitance.

Gate drivers can be assembled from discrete components, but integrated parts are available, for example the EiceDRIVER™ family from Infineon. Parts are available with isolation ratings up to reinforced grade for switches rated up to 2300V, with core-less transformers providing isolation capacitance at sub-pF levels. Comprehensive protection is included against short-circuits, out of tolerance supply rails, and over dissipation of the switch, monitored by de-saturation detection.

Although gates of IGBTs and Si or SiC MOSFETs appear as just a capacitor to the drive (GaN HEMT cells look more like a forward biased diode), significant peak drive current is required, perhaps over 10A, due to the fast switching edges. The gate driver must be able to supply this with minimal output 'droop' as well as continuous power proportional to total gate voltage swing, total gate charge and frequency. For a large IGBT this can be several watts, but for Si and SiC MOSFETs and GaN, the value is typically much less than 1W. This does though have to be provided from the driver isolated supply rails, typically from DC-DC converters specifically designed for the application. Examples are the MGJ1 range from Murata. These surface-mount parts feature a novel transformer embedded in the DC-DC substrate and supply 1W total with a variety of input voltage options and outputs to suit IGBTs and MOSFETs. Isolation capacitance is 3pF, insulation rating is agency-rated 'reinforced' at 250VAC and the parts are suitable for DC links up to 3kV. Unusually, the parts are characterized for low partial

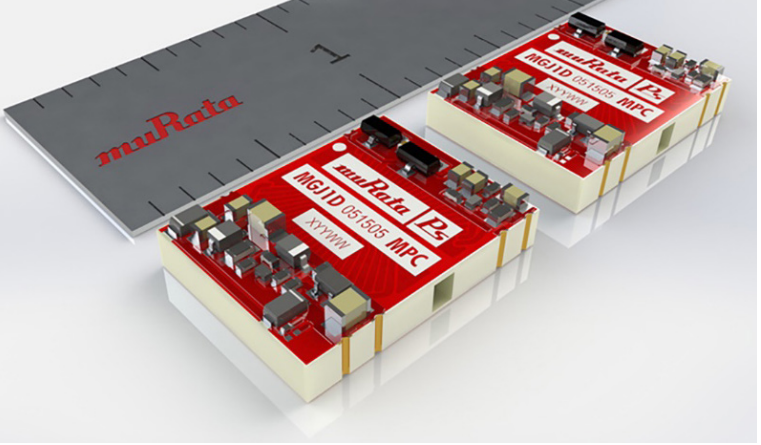


Figure 5:
The MGJ1 series DC-DC converters from Murata, suitable for high-performance gate drive power

discharge breakdown, the slow degradation of insulation due to progressive breakdown of any micro voids present. Higher power versions of DC-DCs are also available from Murata up to 6W rating, including types suitable for high-power IGBTs as well as Si- and SiC MOSFETs. Versions are also available with up to four bi-polar, isolated outputs to provide power for all the gate drives of a full-bridge converter. Aimtec also offers through-hole DC-DCs intended for the application. Articles give guidance on the selection of DC-DCs for gate drives in a typical EV application.

Implementing control

In a traditional AC-DC converter, there is a range of dedicated control ICs available for the PFC/rectification and DC-DC conversion stages, some analog, some with a degree of digital control. Some 'combo' devices even control both stages in one chip. However, the demands of an EV charger are such that these solutions are generally insufficient, not only for the complex, sometimes bi-directional power conversion topologies and control algorithms utilized, but also because an EV charger by its nature has a host of other functions. We have already discussed the digital communications necessary between charger and EV, between the energy provider and the charger, for scheduling, back-feeding, data analysis and billing, and additionally between the charger and the user via some wireless interface and/or card reader. All this means that invariably, overall functionality is implemented by one or more microcontrollers and therefore embedded software must be secure against tampering and malicious attack, while open for legitimate 'over the air' updates and data interchange. With higher-power EV DC chargers being typically assembled from multiple sub-units, each one must additionally communicate with the others for load sharing, load shedding actions and fault reporting. This could be done through a CANbus™ interface, but might now be done with a single-pair low-speed ethernet connection with high noise immunity, using controllers such as the NCN26010 from Onsemi. IP-based communication allows convenient access through simple web-browsers for diagnostics and configuration.

For the main controller, the Infineon XMC 4000 series is a candidate with a 32-bit Cortex®-M4 core operating up to 144MHz. The controller is optimized for real-time applications, ideal for fast control of power conversion algorithms when coupled with high-resolution ADCs, timers and PWM modules.

When security and functional safety are of prime concern, such as with public chargers, the Infineon AURIX™ family is an alternative such as the TC3Ex. These MCUs scale from single to multicore options and can operate in ambient temperatures of up to 150°C. Safety is supported in hardware by a range of mechanisms, including the use of lockstep cores, redundant peripherals, memory protection, clock monitoring and more. The packaging of these devices is designed to be highly scalable, allowing designers to move easily to MCUs with more features when required. As with all Infineon MCUs, the AURIX™ range also offers long-term availability.

The AURIX™ MCUs feature up to 6 MB of flash memory, operate at up to 300 MHz and include a range of high-speed interfaces, including CAN-FD and Ethernet. The direct memory access (DMA) is capable of operating without the CPU, leaving more performance available for the application code. The control of power conversion algorithms is supported by a 12-bit ADC sampling at up to 5 Msps, coupled with timer peripherals that provide a flexible range of pulse-width modulated (PWM) control outputs. Finally, security is ensured by a Hardware Security Module (HSM) that provides an 'anchor of trust', being in a separated logical protection domain. Supported by its own 32-bit MCU, the HSM offers secure boot, secure storage of encryption and authentication keys, along with an AIS31-compliant true random number generator (TRNG) and with hardware acceleration for symmetric and asymmetric cryptography.

Another ARM-based solution is to use the STM32 microcontrollers from STMicroelectronics. Operating up to 170MHz, the parts include five fast ADCs, seven DAC channels, seven ultra-fast comparators, six opamps, timers, a calendar real-time clock and a wide range of communication interfaces. A math accelerator and 512kbytes of flash memory are supported. Parts in the range feature high-security with AES encryption and a public key accelerator (PKA), side-channel hardware-resistant.

Securing the process

The process of charging an EV in public locations and making payment must include identification, authentication and safeguarding of information passed between the charger, vehicle and back-end infrastructure. To achieve this, cryptography is required in data communications within the charging eco-system. As described earlier, standard ISO 15118 introduces the concept of 'Plug and Charge', eliminating the need for a dedicated charging card to be presented. This enables a secure and convenient transaction in both wired and wireless, AC and DC charger systems. Confidentiality, data integrity and authentication are assured, using algorithms defined by the standard for symmetric and asymmetric cryptography.

Infineon offers an implementation of the requirements with their tamper-resistant security controllers OPTIGA™ TPM (Trusted Platform Module) and OPTIGA™ Trust, which enable a secure channel of communication, independent of the connectivity methodology (***Figure 6)***.

The OPTIGA™ TPM parts have a secured key store and support a variety of encryption algorithms and are based on Trusted Computing Group (TSG) standards. The OPTIGA™ trust family of parts are hardware-based security controllers, protecting against counterfeiting and cloning, attacks and unintentional operator errors. OPTIGA™ parts can also be used for platform protection, securing remote functionality such as firmware updates, maintenance and management of the charging infrastructure.

The STSAFE-A110 parts from STMicroelectronics in an SO8N or UFDFPN8 package also provide secure authentication and data management services to a remote host via a cloud connection. The devices utilize the latest generation of highly secure MCUs with a unique die serial number. Advanced symmetric and asymmetric cryptography is employed using a secure operating system, with protection against logical and physical attacks.

The human-machine interface

Some highway chargers have no controls at all, and all authentication and billing functions are through a 'plug and charge' arrangement. A display is typically still required however, to indicate status. The display type needs to be suitable for outdoor viewing in strong sunlight and over widely varying temperatures. A product such as the Tianma P0700WVF1MA00 seven-inch TFT LCD might be suitable, with WVGA 800 x 480 resolution and a 1000:1 contrast ratio. The display uses a Low Voltage Differential Signal (LVDS) interface which provides simple high-speed communication over twisted pair cabling.

The Human-Machine Interface (HMI) may well be a subsystem within any charger, from the simplest AC wall box to the most complex fast DC charger. As such, it could have a dedicated microcontroller with wireless and wired interfaces, along with functions such as a touch controller, LED and LCD drivers from Microchip for example, and audio for spoken input commands and feedback to the user. The charger may have a Near Field Communication (NFC) device or card-reader in which case integrated controllers are available such as the PN5180A0ET range or the PN5321A3HNC/Cxx from NXP, which supports all popular operating modes with an SPI I²C High Speed UART (HSU) interface. Suitable antennas are offered by Molex.

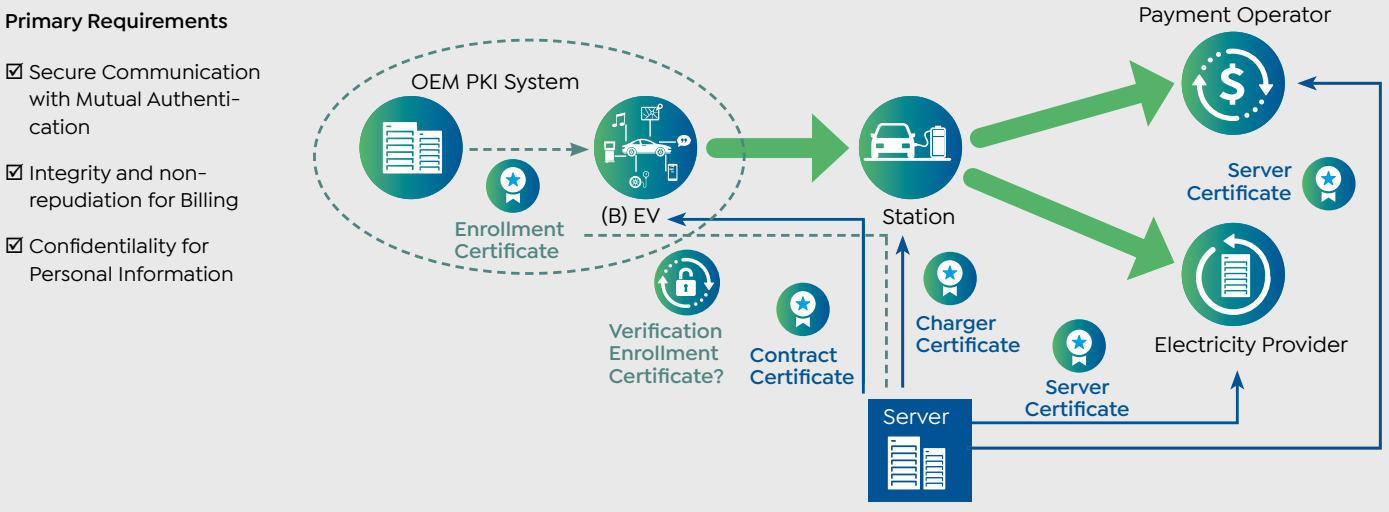


Figure 6: *Securing an EV charging ecosystem using security controllers. Source - Infineon*

General requirements of control electronics

Auxiliary PoL and DC-DC converters

AC and DC chargers will typically include an AC-DC converter for auxiliary power and 12V output would be a popular choice for functions such as relay drives. Suitable products were discussed in the EV charger 'Power Conversion' design guide. Other lower voltages however will also be needed for processors, displays and interfaces and these can be derived from isolated DC-DC or Point of Load (PoL) converters. An isolated DC-DC converter may be chosen when it is useful to separate power grounds for functional or EMC reasons, as well as to generate a different lower or higher voltage efficiently. Communications interfaces also often require isolated power rails for safety and to avoid ground loops between equipment. A wide range of parts is available from Murata Power Solutions, Aimtec, and BEL in surface mount and through-hole variants. The simplest isolated DC-DCs are unregulated and depend on a fixed, regulated input to keep their output typically within +/-5% of nominal while often requiring a minimum load of perhaps 10% of rated maximum.

Point of load converters are used when isolation is not necessary and are always regulated so will provide a precise output voltage over a wide range of input voltages and output current. PoLs are often used with processors or other complex logic such as FPGAs, ASICs and memory, to provide the accurate low voltage power rails required. Despite often providing high step-down voltage ratios, PoLs can be very efficient, typically over 97%, helping to keep overall system efficiency high and temperature rises low. Manufacturers such as Flex Power Modules have a long pedigree of supplying high-performance PoLs and have a wide range available. TDK claim the world's smallest 15W PoL in a 3.3 x 3.3 x 1.5mm package while ABB offer their 'Hornet' PoL range, designed for demanding industrial applications with power ratings to 108W for a surface-mount device (***Figure 7***).



Figure 7: *The ABB 'Hornet' range of surface-mount PoL DC-DC converters*

Hardware security sensors/switches

Although an EV charger sometimes has an entirely touch-display with authentication control and billing all implemented wirelessly, some designs will feature individual touch switches, and these need to be tamper- and vandal-proof. The IP67-rated 'TTS' range from Schurter is a good example of a robust, stainless-steel type that features optical sensing and an innovative 'time of light' technology that sets a detection distance. This ensures that wiping or cleaning does not trigger a switching malfunction. The switch offers bi-color ring illumination in red/green for optical feedback. For charger maintenance, a keylock switch restricts access and provides an electrical interlock which could disable dangerous voltages or just signal that a cover has been opened. Suitable parts are available from TE connectivity. Separate un-keyed anti-tamper switches that might be used internally in a charger are available, such as the IP54-rated surface-mount ATS series from C&K.

Withstanding a difficult environment

It can be expected that any EV charger, from home AC installation to fast DC types will be fitted in an outside location with all of the potential environmental stresses of temperature and humidity, with the possibility of dust ingress, pollutants and even a salty atmosphere in coastal locations. Power connectors to the vehicle mentioned earlier would typically be rated for ambient temperatures of -30°C to +50°C to practically include all locations worldwide but the Amphenol type referenced also includes a temperature sensor to protect against the additional ohmic heating from passing the charging current. The connector might be IP44-rated, providing protection against water splashed from all directions and solid objects over 1mm in size. Smaller objects down to the size of dust are not a major problem in connectors are they have large safety creepage and clearance distances between connections and can be routinely cleaned easily. A DC EV charger itself is subject to significant internal heating on top of the wide variation in ambient temperature and fans are never an ideal solution for lifetime considerations, so thermal management is a major issue addressed during the design phase. As a minimum, industrial temperature grades of components will be used with passive components such as capacitors rated at 105°C or even higher. The use of wide band-gap semiconductors for their potentially better efficiency reduces dissipation and they also inherently operate reliably at higher junction temperatures. This feature has been exploited in server power supplies to allow higher operating temperatures with reduced heatsinking and consequent better power density. However, in an EV charger, this is less of an issue and lower temperature rises will be targeted for reduced component stresses.

An EV charger will also include sensitive PCBs which will typically be coated to provide protection against humidity and the real danger of damp dust causing leakage across tracks or even arcing. The EV charger housing might also include an enhanced protection rating, perhaps IP65 according to IEC 60529 or higher, which give complete protection against dust ingress and low-pressure jets of water. The NEMA standard for enclosure sealing might also be used with Grade 6, for example, providing dust resistance and immersion-proof sealing. Unlike the IP ratings, the NEMA system also has optional further specifications/codes for corrosion and snow/ice resistance which would be particularly relevant to EV chargers (***Table 3***).

NEMA Code	IP Code
1	IP20
2	IP22
3, 3X, 3S, 3SX	IP55
3R, 3RX	IP24
4, 4X	IP44, IP66, IP65
5	IP53
6	IP67
6P	IP68
12, 12K, 13	IP54

Table 3: *Equivalence of IP and NEMA enclosure ratings*

Reliability, lifetime and maintainability

EV chargers can range from relatively simple wall boxes to fast DC types that can include thousands of components, some by their nature stressed with high currents, voltage and temperatures. To maintain high reliability during service, components will be derated appropriately to manufacturer's recommendations. It is accepted that temperature shock can be more damaging than a continuous low or high value, due to stress from differential material expansion, so measures may be put in place to mitigate the effects. For example, it is possible to include simple resistive heaters to gently bring temperatures up to a minimum value for startup from cold temperatures until self-heating takes over, at which point the heaters are disabled.

The likelihood of a random failure during lifetime is a statistical measure, so even if a design has a high Mean Time Between Failure (MTBF) rating, this only reduces the

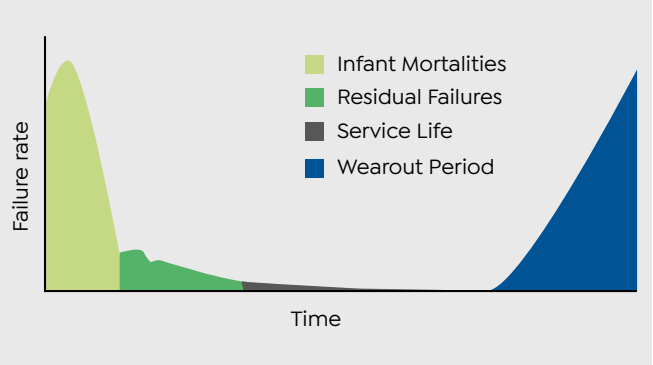


Figure 8: *The reliability 'bathtub' curve*

chance of failure occurrence, which is approximately constant during the bottom of the 'bathtub curve' for failure rate (***Figure 8***). Failure rates are additive in a system, so if any one causes shutdown, in a system with many components, the MTBF for the system can be just a few tens of thousands of hours, even with high quality components. If you take just one charger, the math says that the probability of survival to the MTBF hours is just 37%, *if the system has not reached end of life from wear-out.* For a larger and larger population of installed chargers it can become more certain that across the population, there will be increased numbers of failures starting from the day of installation, even if it is assumed that a burn-in process has eliminated 'infant mortalities. A seemingly good MTBF of 50,000 hours means across 50,000 installed systems, *one per hour* can be expected to fail from day one and service personnel must be available to rectify these faults within the agreed response time. As mentioned before, a high-power charger is typically assembled from independent sub-units which multiply up the power available. While not providing true redundancy, this arrangement does allow continued operation after a failure but with reduced capacity. It is vital that monitoring circuitry senses and reports a sub-unit failure before more occur, but repairs can at least be scheduled at a convenient time.

An EV charger may have high reliability with a high MTBF but lifetime could still be low with a sub-optimal design. For example, electrolytic capacitors can be very reliable but during a very short life. If run near maximum voltage, ripple current and temperature ratings, lifetime could be measured in just weeks, although the definition of failure may be a parameter out of specification such as leakage current, which may not affect operation for a longer period. Derating can increase electrolytic capacitor lifetime dramatically, but can force the use of larger, more expensive components. Large capacitors may therefore be service items, changed out regularly to 'reset' the product expected life. Other components that wear are anything mechanical, such as fans, switches and relays, but also optocouplers and surge limiters such as varistors.

It is inevitable that EV chargers will require regular servicing, if only to clean out any accumulated pollutants. However, the technique of 'predictive maintenance' can be employed, which uses real-time remotely-monitored performance data and its trends to predict if a system is deteriorating and is more likely to fail. Servicing can be performed in advance in 'quiet periods' and only as necessary, allowing far more efficient use of maintenance personnel and resources. It can also avoid the expense of unnecessary changeout of otherwise serviceable components, just because they have operated for a certain number of hours. Typical parameters that might be reported, perhaps over the 'cloud' are internal ambient and component temperatures, system conversion efficiency and electrical noise levels. Many control components incorporate sensors which can be used to compute these parameters and particularly, power conversion performance can be reported through a standard PMBus™ using an I²C interface for example to connectivity modules.

Discrete versus module rationale

It is a well-rehearsed argument, but for a quick time to market for an EV charger, modules or sub-units are available that largely eliminate the risk of discrete ground-up designs. The concept can range from using a modular DC-DC converter instead of discrete components, all the way to implementing reference designs from suppliers such as Infineon for multi-kW power conversion stage sub-units which can be paralleled up to any power level required. Modules can be pre-certified for safety and other standards compliance and come with a track history of field reliability data. An example is the 11kW reference design from Infineon REF-DAB11KIZSICSYS (***Figure 9***) which is a bi-directional DC-DC converter using a CLLC resonant topology, providing 550-800VDC output from a 750VDC input. The design showcases Infineon's CoolSiC™ MOSFETs, Aurix™ and XMC™ controllers along with the OPTIGA™ Trusted Platform Module and EiceDRIVER™ devices, all previously mentioned.

A modular AC-DC 50kW concept reference design is also available from Infineon which is bi-directional and can be air or liquid cooled (***Figure 10***). The design is highly efficient and the output can range from 200 to 900VDC for compatibility with all charging standards and battery types. Use of a reference design gives customers a hardware and software 'blueprint' to dramatically reduce design effort. The designs can be used as sub-units and stacked to achieve the highest current power levels in use and are fully supported with firmware and a GUI for easy setup.
In the area of charge controllers, modules are available from IoTecha. (***Figure 11***) These Systems-on Modules are solutions for the Combined Charging Systems standards in a wide variety of configurations. Among a host of functions, the modules handle authentication, energy and metering management and all necessary communication interfaces to connect to a central server to achieve 'Plug and Charge' functionality. In the area of connectivity, modules for Bluetooth™, Wi-Fi etc. are already effectively considered to be 'components' and bought-in parts are an expedient solution.

Component quality

Components in EV chargers are not required to meet automotive AECQ standards although many parts will be qualified to these levels anyway. In many ways, the internal components will be subject to similar environmental stress to in-vehicle electronics, except perhaps for shock and vibration, so high-grade industrial parts are expected to be used with second sources where possible. A robust design will use parts from established suppliers who are supported by a reliable distribution network with a global presence.

The next part of this series of EV charger design guides will consider connectivity and the final part, software.

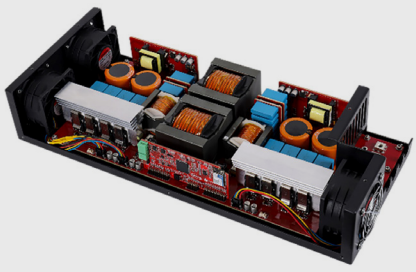


Figure 9: *An EV DC-DC bi-directional charger reference design from Infineon, rated at 11kW*

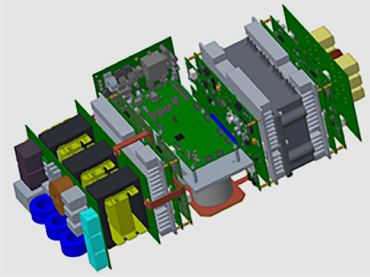


Figure 10: *A modular 50kW EV DC charger reference design from Infineon*

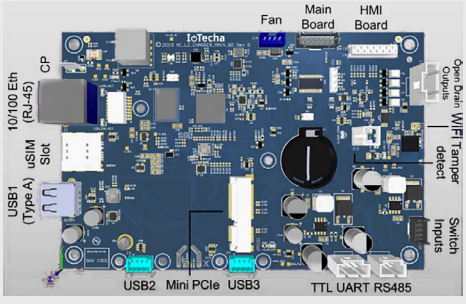


Figure 11: *The IoTecha EV charge controller – a unified platform for AC and DC chargers*

Questions?

If you have any questions about the topics discussed in this guide, or you're ready to take the next step with your design, **reach out to our EV charging expert** - they're some of the best in the industry.


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