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Safety Design of CHAdeMO Quick Charging System

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Abstract

At present, low-output 1 to 2 kW AC electric vehicle chargers are the norm for the charging infrastructure installed in residential areas and business offices. In order to shorten the charging times, there is a belief that it would be best to implement changes that would increase the kW output. However, an objective look at the conditions surrounding the charging process shows such modifications are not necessary. There is a sufficient amount of charging time available and the upgrading of the distribution power grid would require the installation of additional high-power electrical equipment that would ultimately burden users.

Nevertheless, in some cases, fast charging is necessary. Hence, in order to fulfill this need, the installation of a moderate number of quick chargers would be more effective than increasing the output of the individual AC chargers in a halfway manner. The role of this quick-charging infrastructure would primarily be supplementary and in order to achieve a substantial reduction in the charging time, the output would have to be boosted up to around 50kW. Such upgrades would increase the risks associated with high voltage electricity such as electric shocks, burn injuries and fires.

Therefore, after taking these risks into consideration, the CHAdeMO quick charger was designed so that general users will not be exposed to any unnecessary danger when charging their EVs. A report of the CHAdeMO quick charger design features is as follows.

Keywords: Quick charger, CHAdeMO, Infrastructure, DC charger

1. Potential risk of high power electrical equipments

In designing a high power charger for the general public, the potential risks involved should be correctly recognized. Since ordinary people from all walks of life will have access to these quick charging infrastructures, a careful safety design is of utmost importance.

Although your average person nonchalantly uses electrical appliances with an output of less than 1kW on a daily basis, having the same casual attitude towards equipment exceeding several tens of kW of power could potentially be a sure-fire recipe for disaster.

In addition to the high voltage and current levels, the potential risk connected to the three-phases and the DC circuit is much higher because the consequences of a short circuit can be much severer than a single AC phase.

Although people are aware of the risks involved when the speed of a moving car increases, the dangers inherent in voltage and current increases are not as apparent.

Therefore, in addition to safe design and manufacturing, promoting awareness amongst quick charger users regarding the high risks associated with electricity usage is also essential. This can be likened to the precautions drivers adhere to when pumping gas at gas stations.

2. Standardization of connecter

Discussions on the standardization of the connecter have centered on utilizing the same connector for outputs between 1 to 50 kW.

Given that the safety design is premised on being able to handle maximum voltage and current, the connecter itself must be enlarged. Further, the design and manufacturing should be conducted with enough margin to account for the potential risks connected to life degradation.

On the other hand, for daily use, the connector needs to be small, lightweight and easy-to-use. Fulfilling these requirements in light of the aforementioned safety margin is a challenge that needs to be properly addressed.

Some types of EVs do not need quick chargers. For drivers using these EVs, large connecters are not convenient and are very costly. Integrating low and high output into a singular connecter may be good from a mass-production perspective, but leaves much to be desired from other aspects. Therefore, usage should be in accordance with the varying risks. In other words, the connectors should be individually designed to match the charger's output level whether high or low.

In addition, the connecter for the quick charger needs to be designed taking into account the safety design of the entire charging system as it is not possible to create an optimal connector design independent from the design of charger system. The following chapters will explain the safety aspects CHAdeMO quick charger's design.

3. Design concept of CHAdeMO quick charger

As illustrated in Figure 1, the CHAdeMO quick charger design has a controller that receives EV commands via a CAN bus, and the quick charger sets the current to meet the EV's command value. Via this mechanism, optimal and fast charging becomes possible in response to battery performance and the usage environment.

Figure 2 shows the internal structure of the quick charger. In order to prevent accidental high voltage penetration, there is a transformer separating the power grid and the battery system.

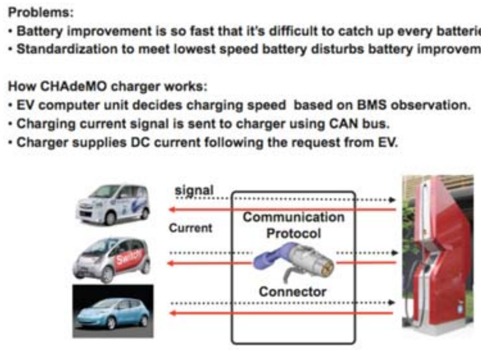


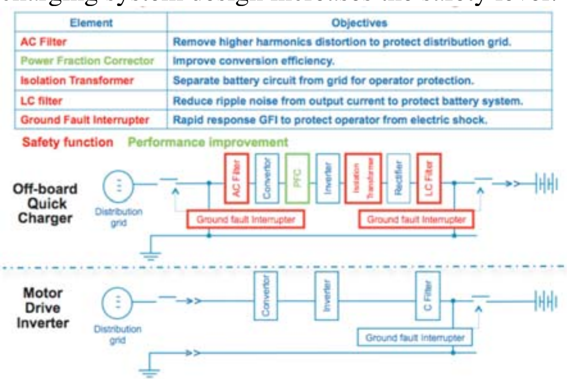
Figure 1: EV and charger relation

The power factor corrector maintains power grid transportation efficiency. An AC filter is installed to remove the negative impact of higher harmonic distortion. In the DC output lines, an LC filter is equipped to drown out ripple noises, which may cause lithium battery degradation.

During the charging process, an "earth leakage detector" probes for potential ground faults in the battery side of the circuit as well as the charger side of the circuit. This equipment allows for a thinner ground wire than the normal protection base ground wire. From a safety perspective, thin ground wire may generally seem like a poor choice because it is unable to bypass high currents in the event of a ground fault accident. However, it is much safer than protection base thick ground wire for current bypasses.

This is because protection ground wire must be kept in sound condition throughout its entire lifespan in order to be able to bypass huge currents in the event of ground fault accidents. However, maintaining the conditions of these wires is very difficult due to poor installation and/or aging degradation.

On the other hand, the earth leakage detector is able to directly detect a ground wire disconnection utilizing an analog signal function, at which point the charging process is immediately shut down. This is a typical example of how the entire charging system design increases the safety level.



Element	Objectives
AC Filter	Remove higher harmonics distortion to protect distribution grid.
Power Fraction Corrector	Improve conversion efficiency.
Isolation Transformer	Separate battery circuit from grid for operator protection.
LC filter	Reduce ripple noise from output current to protect battery system.
Ground Fault Interrupter	Rapid response GFI to protect operator from electric shock.

Figure 2: Internal block diagram of quick charger

Figure 3 illustrates the internal components of the charger. In addition to the switching devices such as the IGBT utilized to convert AC to DC or to invert DC to AC, it has a separation transformer, AC filters, a power fraction corrector, an LC filter, a cooling fan, a control device and sensors for the current, voltage and temperature. Its overall size and weight are approximately 1.5×0.8×0.7m and 400kg.

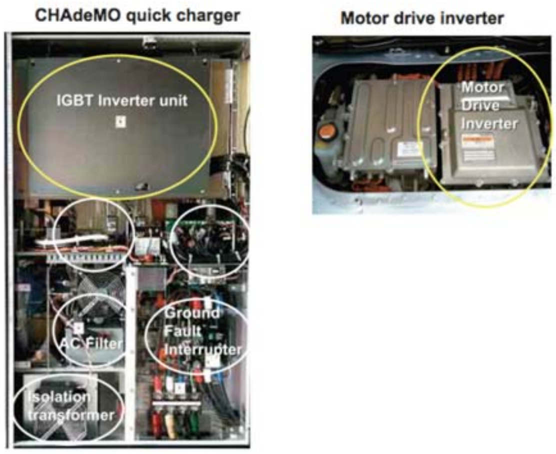


Figure 3: Internal view of quick charger

4. Charging sequence

Figure 4 shows the charging process sequence of the CHAdeMO quick charger. Figure 5 shows the interface structure of the connector between the quick charger and the electric vehicle. Using both figures, I will try to explain how the charging process works.

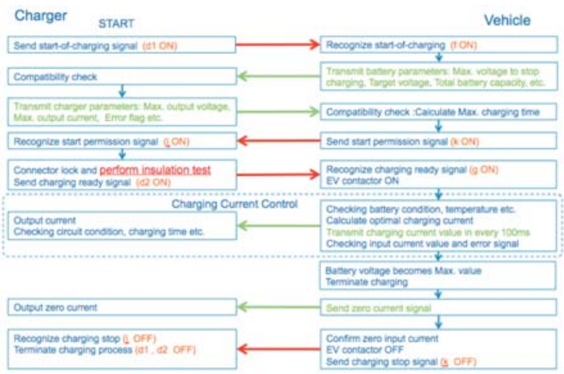


Figure 4: Charging sequence flowchart

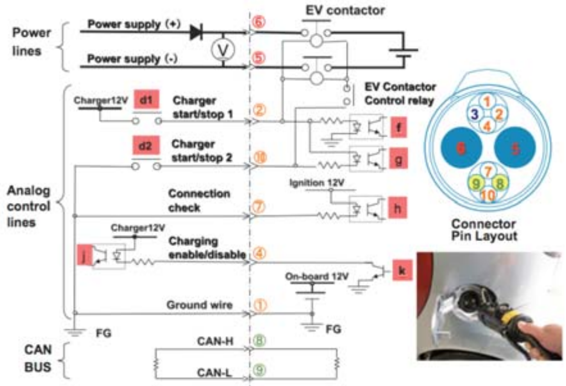


Figure 5: Connector interface

4.1. Preparation for charging

An operator presses the start button of a quick charger which initiates the charging process.

The charger closes the 'd1'relay, and then 12V control voltage is supplied from the charger to a vehicle through analog pin No.2 and excites the photo-coupler 'f'. At that juncture, the vehicle recognizes that the charging operation has begun, and responds by transmitting a parameter such as the voltage limit, maximum current and capacity of its battery system to the charger via the CAN bus. After the charger receives this information and confirms that it can charge the vehicle, the charger transmits its maximum output voltage and maximum output current to the vehicle via the CAN bus.

The vehicle checks its compatibility with the charger based on transmitted data. If it does not find any problems, it sends the permission signal to start charging by conducting the transistor 'k' through analog pin No.4.

Upon receiving this, the charger recognizes that the vehicle has given it permission to begin charging. After the connecter is locked, it applies a short-term voltage load to its exit circuit and conducts a test on the circuit including the connecter interface to confirm there are no abnormalities such as a short circuit or ground fault. Conducting an insulation test before each charging is an effective means to prevent accidents such as short circuit due to aging degradation or the abuse of connecter cables.

When the insulation test is completed, by closing the 'd2'relay, the charger lets the vehicle know that preparations for charging have been completed through the analog pin No.10. The vehicle recognizes this via the photo-coupler 'g', and finally charging is commenced.

This is the preparation process for charging, and actually only takes a few seconds.

It is technically possible to design a charger to transmit all information that passes through via the CAN. However, the combination of analog communication to digital transmission improves the safety level as follows.

a. It prevents the erroneous start of charging due to malfunctions in the digital control system.
b. It can be confirmed that both control systems in the vehicle and the charger are operating correctly at each step of the operation.
c. When the analog signal is lost, the charging operation will be shut down immediately. As the result, shutdowns can be achieved faster than transmitting a digital signal. An important feature of this design is the fail-safe function.

4.2. Start of power supply

After the aforementioned procedures, the charging controlled by the vehicle starts.

The vehicle closes the EV contactor set on the entrance of its battery system.

After this, the vehicle calculates the current level based on the battery performance and circumstances, which can be charged and sends the value to the charger every 0.1-second through the CAN bus.

The charger supplies an electric current that meets the value from the vehicle via constant current control. Throughout the whole charging process, the vehicle is monitoring its battery condition and the current value being supplied. When an abnormality is detected, the supply of the current can be shut down in the following four ways.

1. Send a zero value of output current to the charger through the CAN bus
2. Send an error signal to the charger through the CAN bus
3. Turn off the transistor ‘k’ which sends a NO CHARGE analog signal to the charger
4. Open the EV contactor and the block input current

The charger monitors its condition while charging. It monitors the current, voltage and temperature in each subcircuit, and when any value exceeds the limitations, the charger stops charging and sends an error signal to the vehicle via the CAN bus.

The charger can stop charging in the following four ways.

1. Block the convertor’s gate signal
2. Block the inverter’s gate signal
3. Open the contactor on output lines
4. Open the breaker on input lines

In these ways, the charger has a multiple and diverse safety design that can stop charging in various ways.

4.3. End of Charging

The charging process is completed as follows. First, the vehicle sends zero current signals through the CAN bus, and then the charger stops its output. After confirming the zero current status of the inlet lines of the vehicle, the EV opens the contactor and sends a “prohibit signal” to the charger by switching off transistor ‘k’, and the charger confirms that its output current is zero and opens relay ‘d1’ and ‘d2’.

The role of relay ‘d2’ is to supply 12V control power from the charger to the solenoid of the EV contactor. The opening and closing of the EV contactor is decided by the EV electric control system and performed by the EV contactor control relay. However, since the power of the solenoid of the EV contactor is designed to be supplied from the charger, the EV contactor will not accidentally be closed due to a single failure of the EV electric control system.

Since solenoid power cannot be supplied when the connector is decoupled, the probability that the EV contactor will accidentally close is very small and this design ensures the prevention of an inadvertent high voltage load on the socket pins.

In chapter 3, we explained that it is safe with an earth leakage detector even though the ground wire is thin. In the CHAdeMO quick charger, the ‘f’, ‘g’ and ‘j’ signals of the photo-couplers are lost at once even if the ground wire loses its continuity, the charger stops charging and the EV contactor becomes open immediately. Like this, the pin layout of the connector should be designed in relation to the entire charger system and safety design. It should not be designed independently.

After the charging is finished and it has been verified that the exit circuit voltage is below 10V, the connector lock is opened and the charging sequence is completed.

This is not mentioned in the sequence, analog pin No.7 is used for detecting that the connecter is inserted, and when the operation to get the vehicle started is performed, current flows to the photo-coupler ‘h’ and vehicle ignition is prevented.

Figure 6 shows a change of the typical charging current. After reaching the maximum voltage, the charging current decreases gradually and then the charging is completed.

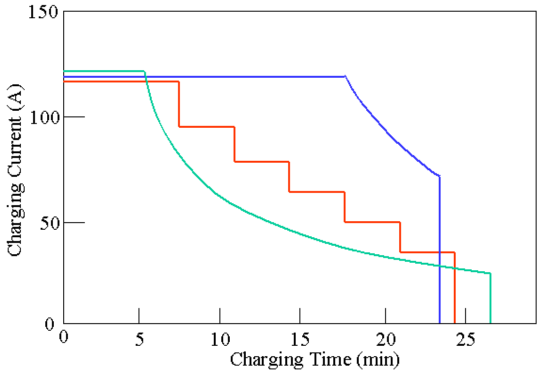


Figure 6: Typical charging pattern

5. Conclusion

The CHAdeMO quick charger uses an analog signal transmission and a digital communication via CAN. This diverse and redundant design ensures its safe operation.

In the design of the DC connector, in addition to having enough safety margin such as an insulation distance, between the power pins, four analog signal pins, two CAN digital signal pins and one ground pin which are implemented so that the control signals can be transferred properly between the vehicle and the charger.

Under a business model that utilizes quick chargers, the certification of EVs and a billing system will be taken into consideration. However, since the reliability of these services are different from the safety functions and the control charging processes themselves, it is appropriate to separate these systems from the charger operation control.

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