Load Control System of an EV Charging Station Group

Antti Rautiainen and Pertti Järventausta
Tampere University of Technology
Department of Electrical Engineering
antti.rautiainen@tut.fi

SUMMARY

When multiple AC electric vehicle charging stations are planned to be installed in a parking hall or other place, a certain issue always arises. If there are many EVs charging simultaneously using high powers/currents, the total peak powers/currents of the cables feeding the charging station group or in the network connection can rise to an extremely high level which leads to needs for very thick cables and/or large main fuse sizes. From the cost effectiveness point-of-view, this is not desirable. However, the widely respected standardized charging method “mode 3” (defined in IEC 61851-1) enables controlling the maximum charging current of an individual charging station, and a control system controlling the total load of a charging station group can be made. In this paper, corresponding control methods are discussed in general, and an example of a practical and generic control algorithm is presented and simulated in detail. The algorithm can be used also for other load control purposes besides management of the sizes of cables and main fuses. The simulation shows that the algorithm works efficiently and is flexible in different operational situations.

KEYWORDS

Electric vehicles, plug-in hybrid electric vehicles, charging station, load control, demand response

1. INTRODUCTION

Today's society is too dependent on oil, and there might be "cheap oil" in the ground less than many people expect [1]. Also, there is a need to reduce the air quality related tail pipe emissions of cars especially in large cities [2]. In addition to these there is also a need to reduce the greenhouse gas emissions of the transportation system in order to participate in the climate change mitigation. Electric vehicles (EVs), both plug-in hybrid electric vehicles (PHEVs) and full electric vehicles (full EV), could be used to partly contribute to these challenges. In the last few years almost all car manufacturers have launched some kind of EVs to the market, and it is widely expected that these vehicles will be "permanently" part of the road transportation system at least to some extent. Of course there are still some challenges in the wide penetration of EVs to the road transportation system which has to be tackled [3].

An EV has to be charged using a charging station or at least a socket. The widely respected international standard IEC 61851-1 defines four different charging modes, and in practice three of them are used in commercial electric passenger vehicles today: mode 2, mode 3 and mode 4. In modes 2 and 3, the charger is in the vehicle and AC voltage and current are fed to the car. In mode 4 DC voltage and current are fed directly to the high voltage battery pack of the vehicle.

The first option is to use mode 2 charging. In Europe, this means that the regular "schuko" socket is used in the charging in most of the cases, and there is a so-called in-cable control and protection device (IC-CPD) in the charging cable. IC-CPD includes some safety functionalities such as a residual current device but it also restricts the charging current of the EV charger to a level (typically 6–10 A) which is safer to be used in domestic and other sockets. Typically every commercial EV is delivered to the consumer at least with a mode 2 charging cable.

The second option is to use mode 3 charging. In practice, this mode is preferred and recommended for the everyday use by the car manufacturers and different kinds of regulative and instructive organizations. Mode 3 enables charging currents from one-phase 6 A up to three-phase 63 A. Mode 3 charging includes many sophisticated, such as safety related, functionalities, but also a possibility to control the maximum current which the vehicle can draw from the socket. It should be noted that only the maximum current level can be set, and the charger itself decides the actual charging current below the limit. In addition to the normal power conductors, mode 3 sockets also include two additional conductors for control and protection purposes: control pilot (CP) and proximity pilot (PP) conductors. The control of the maximum current is made using an analog pulse width modulated (PWM) voltage signal between the control pilot and earth conductors. The maximum current level can be adjusted between 6A and 63 A, and the charger of the car obeys this limit. For mode 3 there are standardized sockets and plugs which are dedicated to EV charging. These sockets and plugs are standardized in IEC 62196 standard family. In Europe, the de facto standard is "type 2" ("Mennekes") socket.

The third charging option is mode 4. This means that the off-board charger feeds DC voltage and current directly to the battery pack of the car, and the car controls the charging voltage and current during the charging. When the charger is an off-board one, it is possible to use very high charging powers. Typically mode 4 charging powers have nominal powers up to 50 kW, but there are also 20 kW chargers available. DC charging is very useful in cases where the battery pack of the car is large and one needs to have battery charged within an hour. The charging current of the car can also be restricted with mode 4 charger by the charging station.

When multiple electric vehicle charging stations are planned to be installed in a parking hall or other place, a certain issue always arises. If there are many EVs charging simultaneously using high powers/currents, the total peak powers/currents of the cables feeding the charging station group or in the network connection can rise to an extremely high level which leads to needs for very thick cables and/or large main fuse sizes. From the cost effectiveness point-of-view, this is not desirable. It might be therefore reasonable to control the total currents of a charging station group. This paper focuses on these kinds of systems. In addition to the cable and main fuse optimization, there might also be some other types of needs for such a control system such as electricity contracts with dynamic pricing [4], distribution tariffs with a power based component [5] and ancillary service opportunities [6]. This paper, however, focuses on the cable and main fuse optimization incentive. The paper is organized as follows. In section 2, some general basic principles and requirements of an EV charging station group's load control system are discussed and a practical and generic algorithm is described. In section 3, the results of the algorithm simulation are presented. In section 4, conclusions are made and future work is proposed.

2. LOAD CONTROL SYSTEM

2.1 General aspects and features

EV charging can be controlled at least in two ways: by switching charging on/off (typically the only option for mode 2 charging) or by restricting the mode 3 (or mode 4) charging current as explained in section 1. On/off switching is simple to realize, but it has to be made in such a way that the control does not interfere the charging system of the car. For example, some models of mode 2 charging related in-cable-control-boxes do not necessarily continue charging automatically after they have been switched on after an off-switching period, i.e. a period without any voltage in the charging socket.

A load control system can be made in many ways and with different features and properties. The main structure is, however, illustrated in fig. 1. There is a group of *N* charging stations and a load controller unit which controls all of the charging stations in some way to manage the total load of the charging station group. In the figure 1, there is also the total current measurement of the feeder feeding the charging station group. Also, it is possible to measure the phase currents of each of the charging stations and send the data to the controller. In principle, it would be possible to construct a control system where the total currents or the currents of individual charging stations would not be measured at all, but this may lead to an inefficient system.

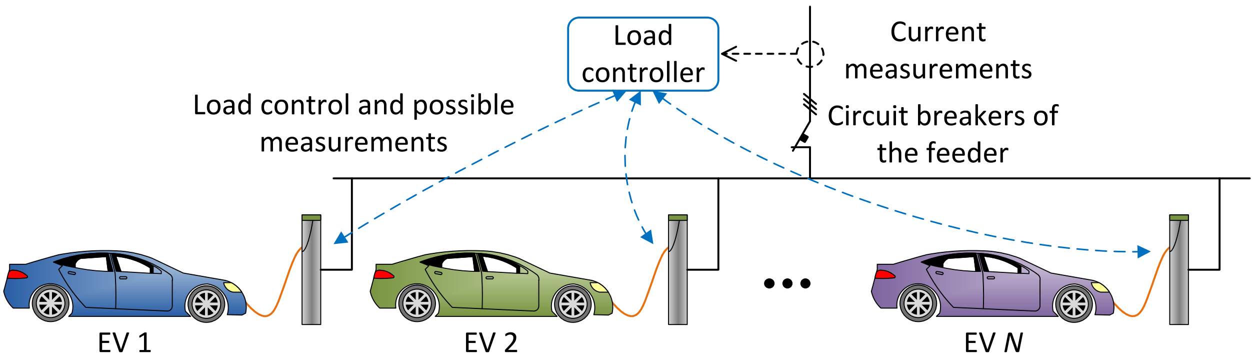

Fig. 1. The basic set-up of a load control system of charging station group.

How the electric circuits or feeders are constructed in very large parking and charging areas poses a question of its own. Typically a few charging stations are connected to a single cable and corresponding fuses and many of these kinds of subgroups exist in a parking area. In such cases the peak currents of the subgroups have to be managed separately in addition to the total current. Also, it is reasonable to circulate the phase sequences of three-phase stations and connection phases of one-phase stations in order to avoid "L1 syndrome", i.e. a situation where one of the phases is overloaded and two other phases carry a very low current. The risk might be realized as the commercial cars with one-phase chargers connect typically to the "L1 phase" of the vehicle inlet.

A real load control system should be fast enough to be able to handle all the situations where fast changes happen in a system. If one of the phase currents were to suddenly increase for some reason, the circuit breakers might open or fuses might blow if the load control system is not fast enough. Circuit breakers tolerate some overcurrent for a while, but the length of the overcurrent tolerant time depends on the amount of overcurrent and the protection device.

2.2 The simulated control algorithm

The purpose of the load control system simulated in the paper is to provide the chargers a very high current capacity as seamlessly as possible in every situation so that the total currents would still be kept below a certain limit. It is assumed that the total current of the feeder and the currents of the individual charging stations are measured in real time and the measurement data is sent to the load controller. The simulated load control algorithm can control chargers using mode 2 and mode 3 charging. In mode 3 charging the pilot wire PWM communication is used to set the maximum current for the vehicle and in case of mode 2 charging is interrupted by disconnecting the charger from the grid. It is also possible to interrupt mode 3 charging using the communication. For mode 3 sockets, one-phase, two-phase or three-phase chargers can be used, and one-phase and two-phase chargers can be connected to any phase of the socket.

In brief, the main idea of the algorithm is as follows. Chargers are allowed to charge whenever needed even with the maximum current of the charging station, but if the total current of any of the feeding phases exceeds a certain predefined limit (the limit can be a parameter which can be changed in accordance of the situation), first restrict the currents of mode 3 chargers if it is possible to decrease the currents of the overloaded phases. If this is not possible or if it does not solve the problem, interrupt the charging of some of the chargers from the relevant phases. The interrupted chargers should be then circulated and alternated so that none of the chargers have to be interrupted for too long. The circulation time is a rigid 10 min.

The algorithm is designed to react to certain events. The essential events are as follows.

1. The current limit is exceeded in some phases.
2. The current capacity is freed in some phases.
3. An EV starts mode 3 charging.

The functions and procedures in the cases of the previous three events are described in more detail in the following flow charts (figures 2–4). The procedures triggered by the events also include some sub processes which are also introduced as flow charts. The flow charts do not describe all the details, but the essential ideas are covered.

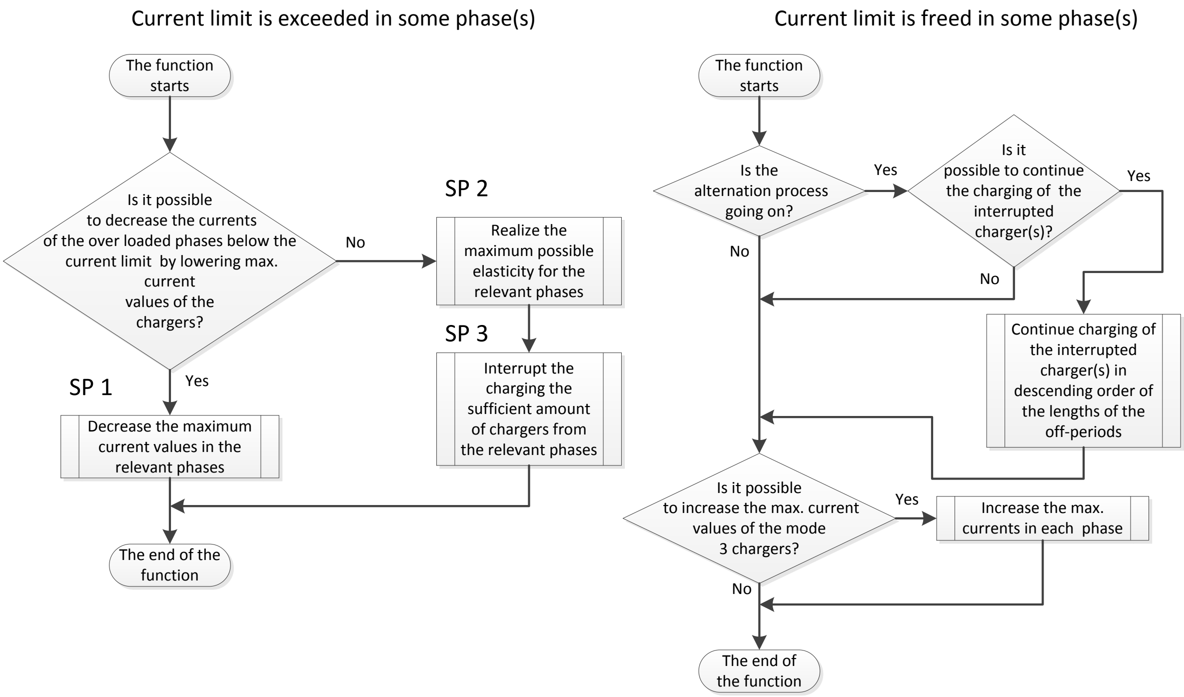

Fig. 2. Functions “Current limit exceeded in some phase(s) and “Current limit is freed in some phase(s)”.

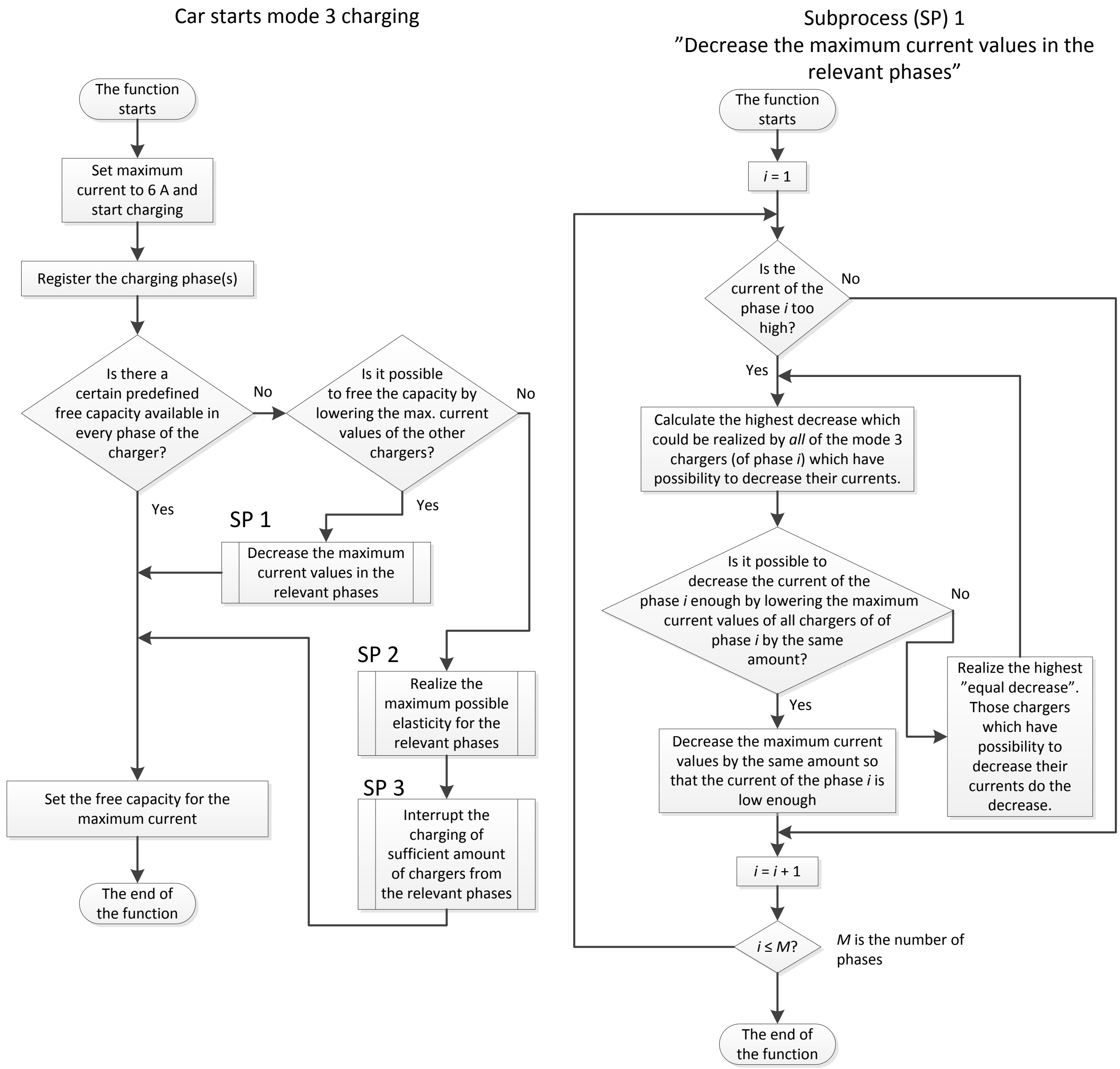

Fig. 3. Functions "Car starts mode 3 charging" and "Decrease the maximum current values in the relevant phases".

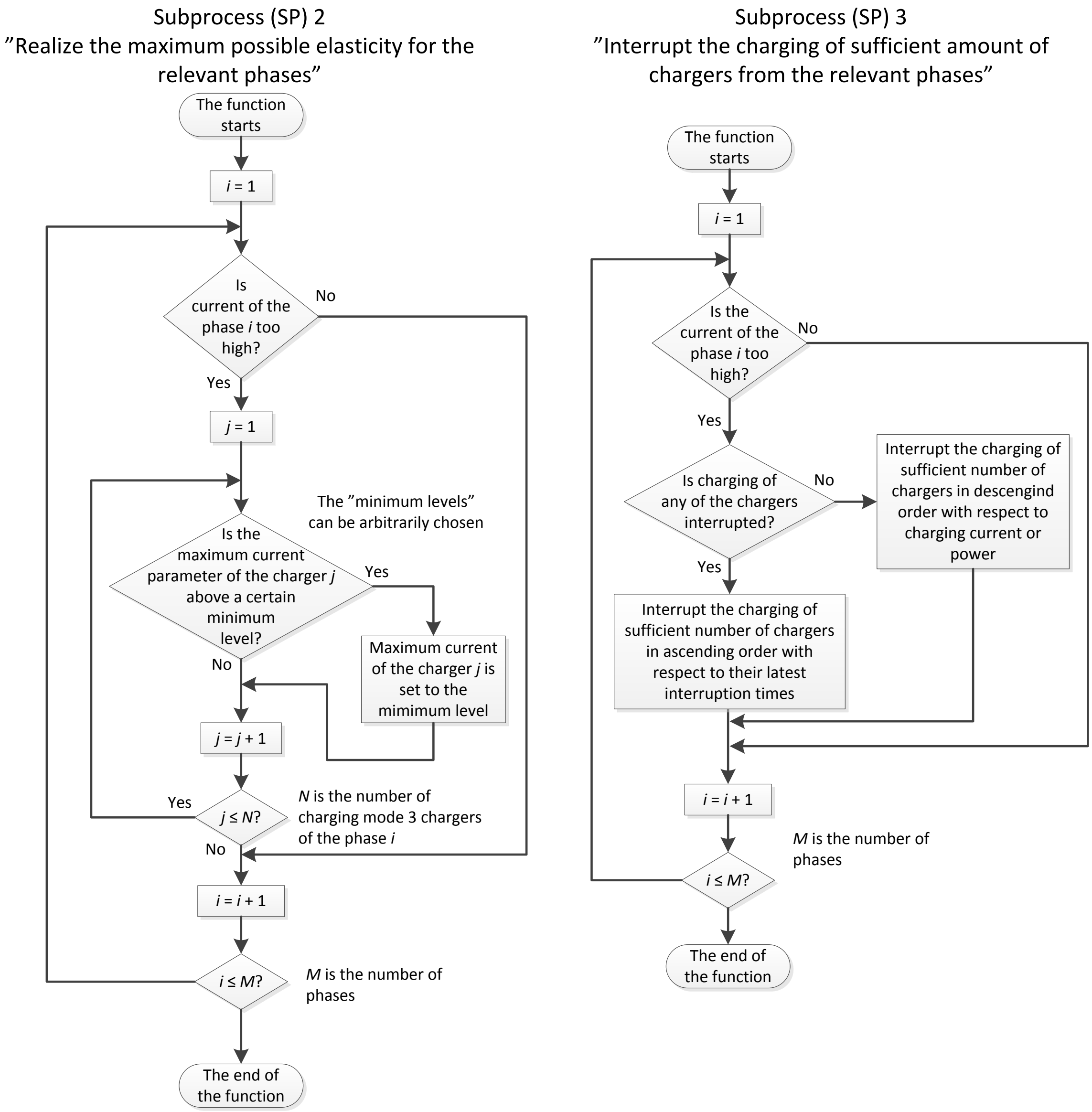

Fig. 4. Functions "Realize the maximum possible elasticity for the relevant phases" and "Interrupt the charging of a sufficient number of chargers from the relevant phases".

3. SIMULATIONS AND THEIR RESULTS

3.1 Simulation case

The algorithm was simulated with a realistic use case. In the simulations the charging behaviors of 10 different EVs were modeled. Fig. 5 illustrates the charging station types and ratings of the EV chargers. There were 6 mode 3 charging stations and four Schuko plugs in which EVs were charged. The time in hours when the cars are plugged in to the charging station, the SOC of the battery pack (in red) at the first time of arrival and the decrease in SOC (in blue) in the beginning of the second charging session were illustrated in the figure. The simulations were made in 1 minute long time steps. Some "inter-minute" phenomena were also included in the simulation code, but the results were presented only on a minute level. In fig 14, also the circuit breakers for all of the phases are presented as the current limits.

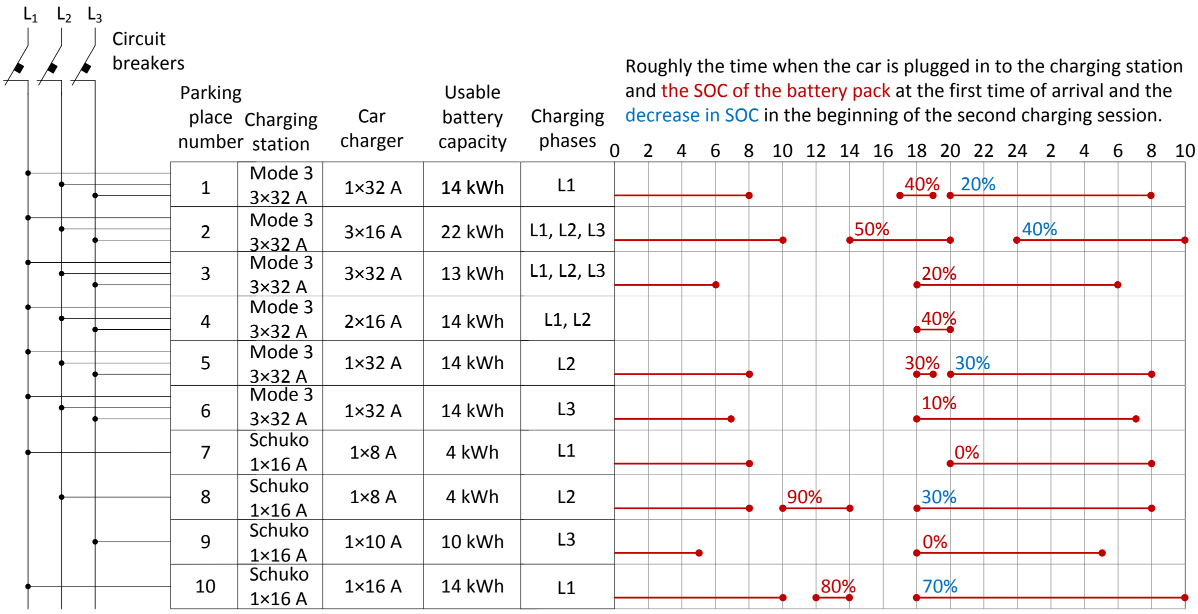

Fig. 5. The simulation case.

3.2 Simulation results

Four different simulations are presented in this paper. The simulations differ from each other in the current limit values. Current limits were “no limit”, 50 A, 32 A and 16 A. The results are presented in figures 6–11. From each current limit, two different figures are presented: phase currents and charging current of the cars. Charging currents of the cars are presented only for one phase, and if a charger is a multi-phase one, the same current is drawn from all of the phases.

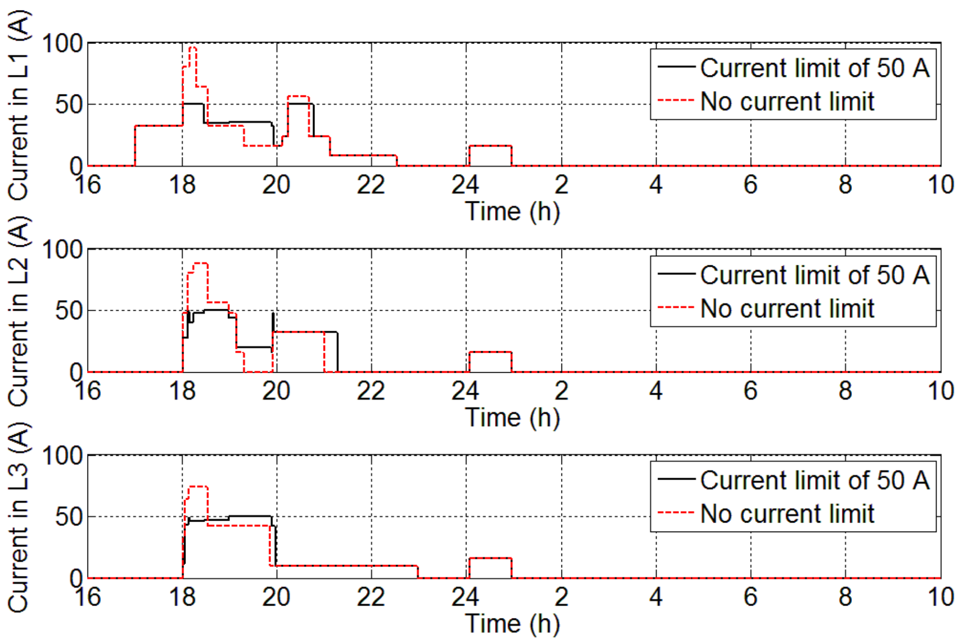

Fig. 6. Phase currents of the case “no current limit” and with a current limit of 50 A.

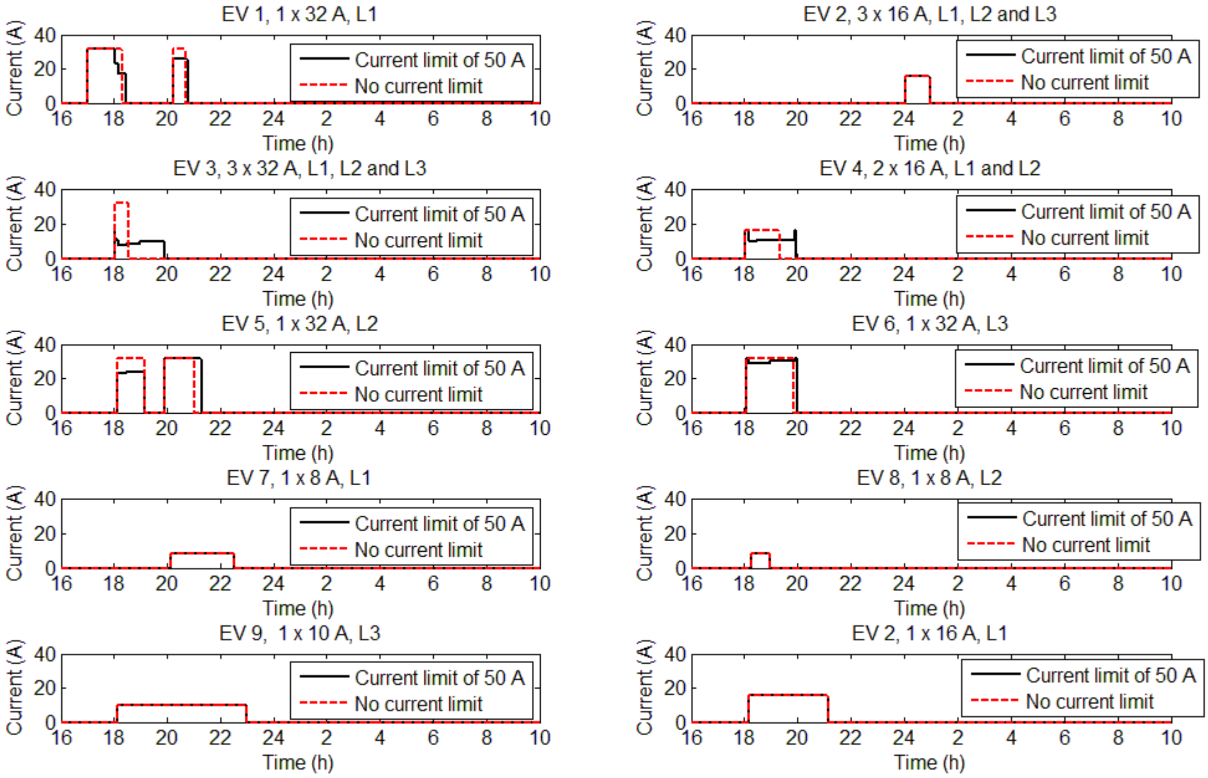

Fig. 7. Charging currents of the cars with no current limits and with a current limit of 50 A.

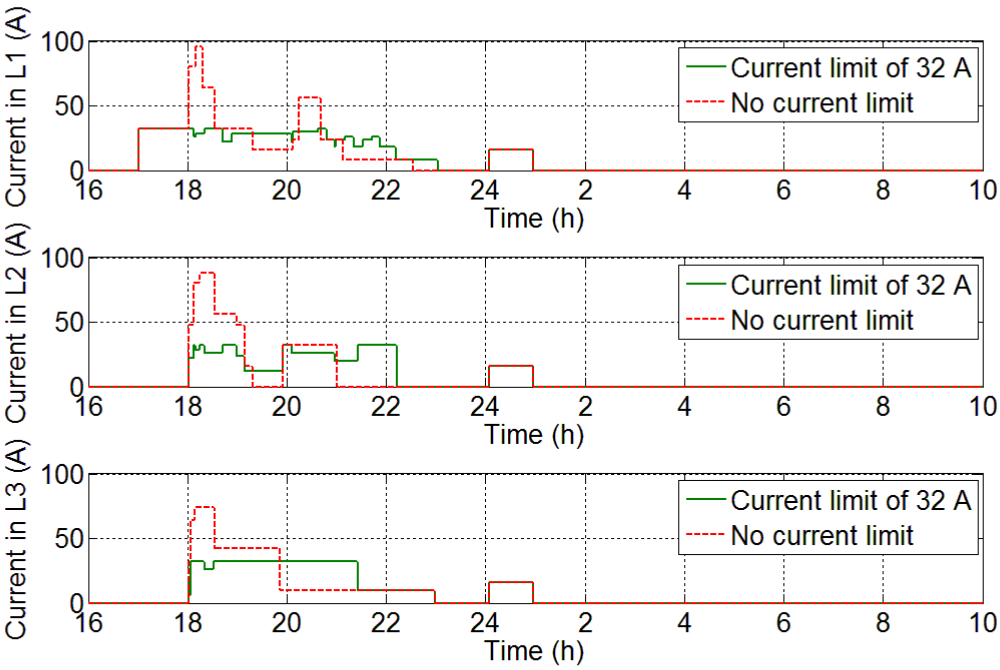

Fig. 8. Phase currents of the case “no current limit” and with a current limit of 32 A.

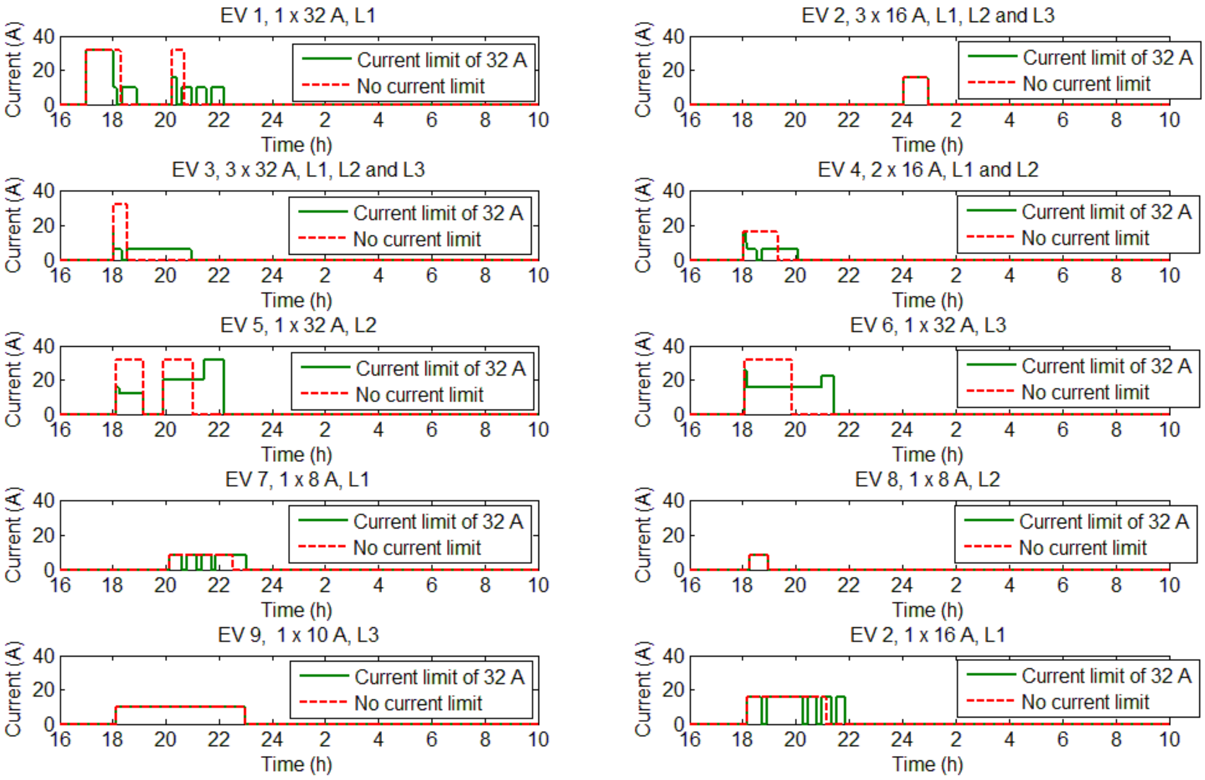

Fig. 9. Charging currents of the cars with no current limits and with a current limit of 32 A.

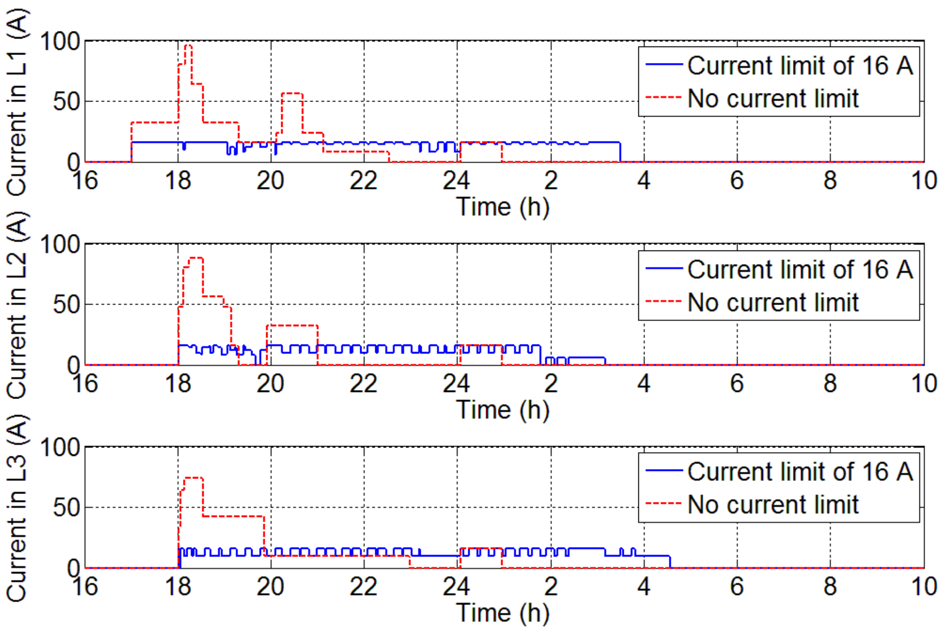

Fig. 10. Phase currents of the case “no current limit” and with a current limit of 16 A.

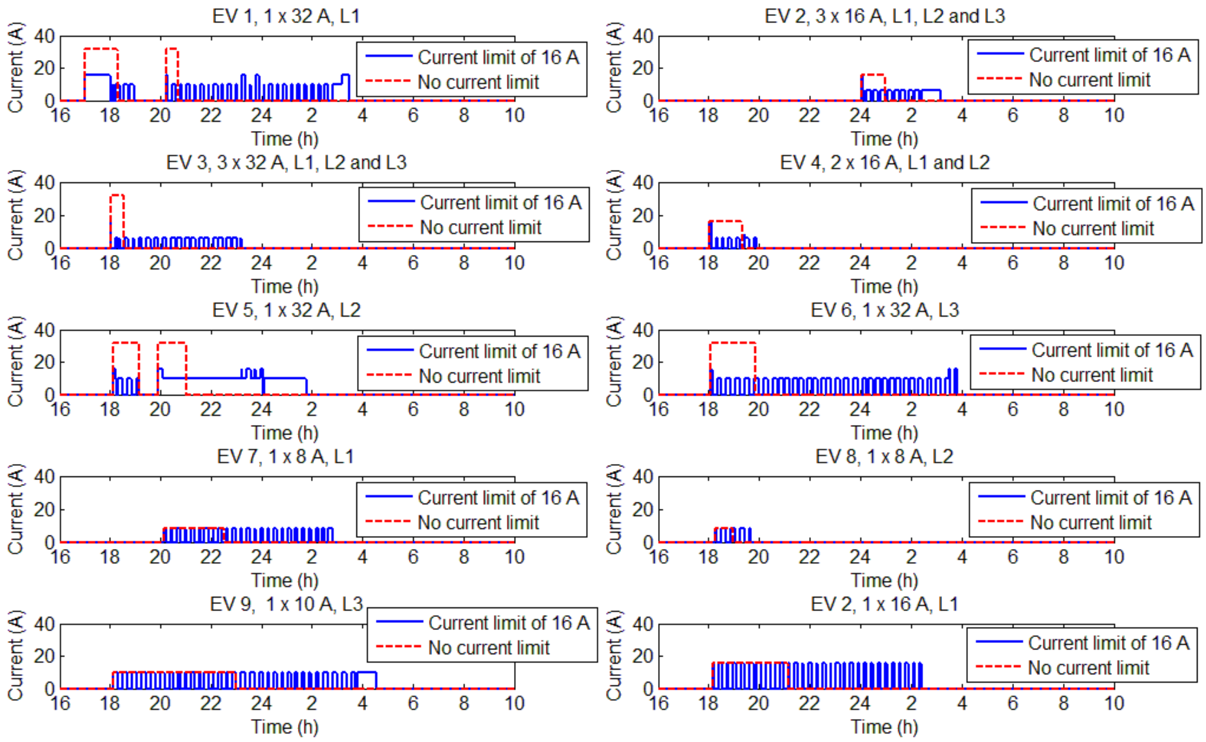

Fig. 11. Charging currents of the cars with no current limits and with a current limit of 16 A.

A few things can be noticed from the simulation results. When there is no current limit, the current of phase L1 rises to a value near 100 A. When a current limit of 50 A is set, some of the cars with mode 3 charging had to decrease their charging currents to keep the total phase currents below the current limit. However, the charging of any of the chargers was not interrupted. When the current limit is decreased to 32 A, the charging currents had to be decreased more and also some charging interruption had to be made. The final 16 A current limit is a sort of an extreme case. As it is allowed that a 16 A current can be taken from the Schuko socket, it is also the lowest possible theoretical current limit in order to make charging possible from all of the charging points. It can be seen that now a lot of charging interruption have to be made to keep the phase currents below 16 A. Also, the charged energies of the EVs do not change except for the EV 4, because it stays at the charging place only roughly two hours.

4. CONCLUSION

In this paper, controlling of an EV charging station group is investigated. A load control algorithm is presented and simulated with a realistic use case. The algorithm is able to control mode 2 and mode 3 chargers, although it is somewhat uncertain whether controlling the mode 2 chargers is reasonable unless it was controlled by communicating directly to the car. It is expected that most of the charging system manufacturers will develop their load control systems for mode 3 charging only. The simulated algorithm seems to be very flexible with respect to different types of charging modes and charging load situations. Also, the mode 3 charging control needed in the system is already implemented in every commercial EV on the market.

The studies of the paper raised some topics for future work. The algorithm could be developed in many ways. If charging stations had information about the states of charge of the battery packs, the algorithm could be made to take that into account. Also, real demonstrations of the algorithms with real charging stations should be made. The possibilities of these kinds of systems realizing different energy related ancillary services should also be studied.

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