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INCH – Interactive Charging of Electric Vehicles

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Summary

The INCH – INteractive CHarging system for electric vehicles developed by Etrel is intended to reduce costs related to EV private charging, which would be inevitable without control of charging load. The system enables, with minimum investment costs, to monitor the conditions at building's grid connection point, and to predict the power consumption in user's internal network. Implemented algorithms enable to control EV charging load in a way that the operation of internal network is safe, the production of local resources is consumed locally, and the EV charging is shifted to periods of low tariffs. The system is also capable to adapt the charging load to the needs of grid operators and energy market actors which results in additional benefit for EV user.

Keywords: EV charging, smart charging, load management, smart grid

1 Introduction

Energy consumed for electric vehicle (EV) charging at home represents a significant share of typical household's total electricity consumption. Usually it far exceeds the consumption of any other appliance supplied from the grid user's internal network; the same is valid also for the charging load which might be substantially higher than the total load of all other appliances.

Increased household consumption and peak load due to EV charging calls for implementation of controlled EV charging that results in:

- reliable operation of grid user's (i.e. household's) internal network without interruptions of power supply caused by high EV charging load and consequent operation of protective devices at grid connection point,
- avoidance (or reduction) of the need to upgrade the household's grid connection point rated power,
- cost-optimised household's consumption pattern.

EV charging consumption affects not only the grid users' internal networks but also the public grid. Uptake of electric mobility and increased electricity consumption leads to a higher load of public grid components (lines, transformers) and deteriorates voltage conditions. Significant impacts are already observed on the distribution level in areas of higher density of charging points and/or with weakly developed grid. In further development of electric mobility, the impacts of EV charging will become evident also on transmission grid level and on national level in form of considerable increase of system peak load. Consequently, the grid operators will be forced to upgrade the existing grid in order to maintain the required quality of power supply, and additional peaking power plants will have to be erected to cover the increased system peak load. The listed system expansion measures require considerable investments into infrastructure which will be directly reflected in grid users' price connected with energy supply (grid connection and grid use fees).

The alternative way to maintain the quality of power supply under new conditions and without unnecessary investments is implementation of active cooperation between system operators and end users (as also emphasised by the EC in the frame of package of measures Clean energy for all Europeans [1]). Involvement of end users in demand response schemes will enable them to support the grid operators in operation of power systems with the mutual goal to avoid excessive investments in the grid. In addition, demand response may also be used for optimisation of energy consumption profiles, leading to decreased overall energy production costs and costs linked to covering of peak demand.

Public charging locations may comprise several charging points and are thus the most suitable grid users to be included in demand response schemes. On the other hand, public charging represents (and will also in the future) only a minor part of EV charging; a major share of EV charging will take place at home, i.e. in households and multi-dwelling buildings (private and semi-private charging). Therefore, incorporation of private charging in demand response schemes is of major importance for grid and energy market operation.

As a response to the needs of EV users, grid operators, and energy market, Etrel developed the INCH system, an integrated solution for management of EV charging load in private and semi-private locations based on interactive AC charger. The solution controls EV charging in interaction with operation of grid user's internal network with the final goal to increase the reliability of network operation, minimises required EV user's investments into internal network, optimises the costs linked to delivery of energy, and supports the grid and energy market actors in their operation.

The system was developed within the INCH project which has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 699111.

2 Requirements for interactive charging system

The INCH charging system is designed with consideration of EV users' charging needs which are reflected in the system's technical requirements.

2.1 EV user needs

The EV user needs, related to private or semi-private (multi dwelling buildings) charging may be classified into four main categories:

- elementary charging needs (to satisfy user charging preferences): delivery of required amount of energy during the time available for charging, access to charging information;
- safety needs: EV charging load shall not endanger the operation of user's internal network;
- economic needs: costs of charging and of charging system implementation shall be as low as possible;
- shared use needs: charging system shall allow different users to access the charger(s).

2.2 Technical requirements

In order to satisfy the EV user needs the interactive charging system fulfils the following requirements:

- charging system shall be capable to determine the user charging preferences;
- charging system shall be capable to control the charging load by consideration of total building's load;
- charger shall support different communication interfaces to connect to the home network and to grid and energy actors;
- charging system shall enable advanced local power management for optimisation of total building's costs for energy delivery, for charging load control depending on grid frequency (relevant for grid operation on isolated, self-sustainable islands), and for distribution of power available for charging to individual chargers located at the same location (relevant for semi private charging).

3 System architecture and components

3.1 System architecture

The INCH charging system is composed of two main components:

- home charger (or several chargers, clustered at the same location, i.e. behind the and fed via the same grid connection point), and
- Load guard, a device that measures the conditions at grid connection point (phase currents, active and reactive power, frequency).

The most complex architecture where all system actors and subsystems are present is presented in Figure 1:

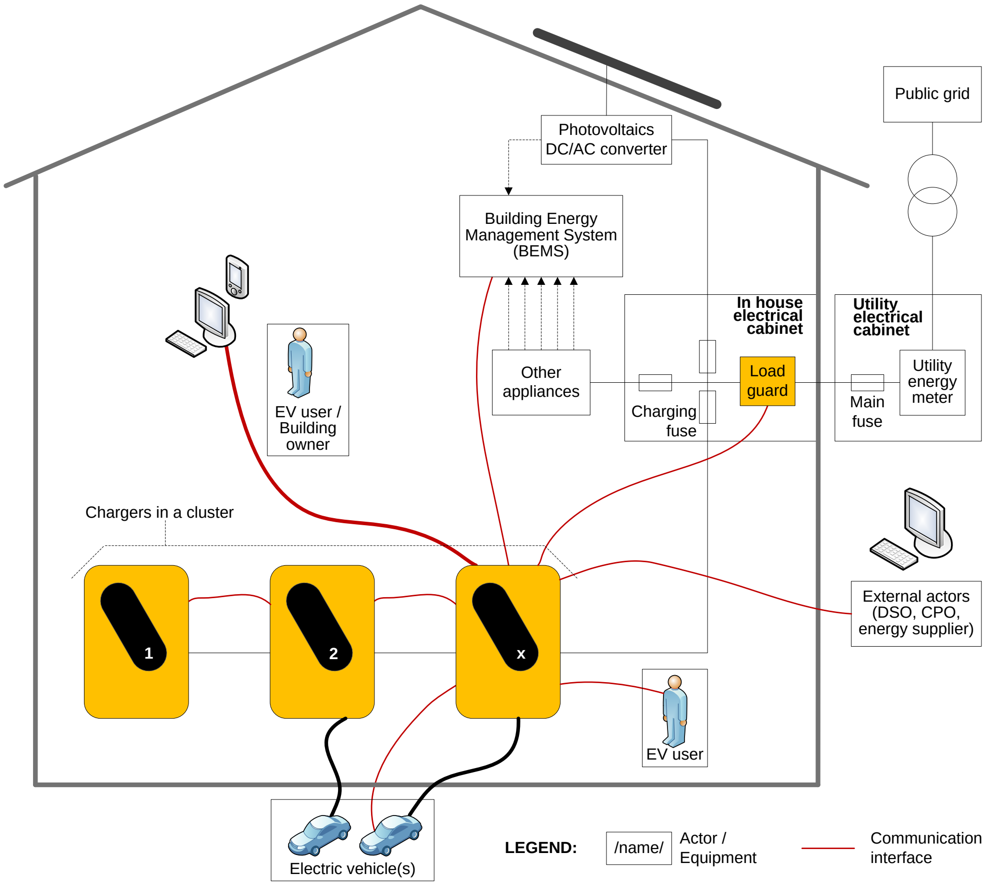

Figure 1: INCH charging system architecture

Within the charging system one or several chargers can be installed in the grid user's internal network. In the case of configuration with multiple chargers (a cluster) the chargers communicate among themselves to achieve a coordinated operation of the charging system.

The Load guard device measures the load at the connection point between the public grid (controlled by Distribution System Operator – DSO) and the grid user's internal network. The measured values are communicated to charger with implemented power management algorithms.

The charger is equipped also with other communication interfaces towards external actors such as DSO or actors / components within grid user's (building owner's) internal network, such as Building Energy Management System.

The communication capabilities enable the charging system to execute more or less complex power management algorithms implemented in the charger.

3.2 Charger

The charger enables charging of one electric vehicle with maximum charging current of 3 x 32 A (corresponding to 22 kW at nominal grid voltage). The charger can be equipped with Type 2 socket or with attached cable with Type 2 plug on the EV side, as presented in Figure 2. In the latter case, a special holder (mounting tray) is mounted on the bottom side of charger.

Figure 2: INCH charger with socket (left) or attached cable (right)

The charger's dimensions are 45 x 27 x 13.5 cm. The casing is made from aluminium which is fine grain coloured according to customer's selection. The charger's front plate is made from polycarbonate glass which covers the charger's user interface, containing touch interface over LCD display, RFID/NFC reader/writer, and status LED lights.

The scope of available functionalities supported by touch interface and LCD display depends on charger configuration (home or public charging, identification type, power management type, on-screen advertising, etc.):

- user identification,
- setting of departure time,
- displaying information about basic and exceptional states,
- displaying charging information,
- displaying on-screen charger ads.

The charger can be accessed also via web user interface which enables:

- power management monitoring (review of total building consumption/production and EV charging consumption, review of results and benefits of power management),
- user's inputs needed for execution of power management algorithms (departure time and required energy),
- administration of charging system (configuration of communication interfaces, insertion of EV and internal network data, configuration of energy delivery tariffs, configuration of power management algorithms, administration of local users).

The web interface is accessible through different communication interfaces: Ethernet, Wi-Fi, PLC, or GSM.

3.3 Load Guard device

Load guard is a device for metering the electrical conditions at grid connection point. It is installed in internal network of the grid user, more precisely in the electrical cabinet just behind the utility energy meter and main fuse (see Figure 1). The main output of Load guard is measurement of phase currents (i.e. phase loads of the entire grid user's internal network). The metered values are communicated to the charger which uses them in execution of power management algorithms.

For phase currents metering the so-called Rogowski coils (one per each phase) are used. The current sensors are wired to electronic module. The main part of this module is energy metering integrated circuit (microchip) which executes calculation of active, reactive, and apparent power and energy, and phase voltages and currents. For this purpose, also phase voltages are connected to electronic module.

The Load Guard device is able to communicate with charger via Ethernet or PLC interface. In addition, a JTAG interface is installed on the module to enable programming, testing and calibration of energy metering integrated circuit.

4 SW functionalities

4.1 General description of algorithms

The core of INCH charging system are the algorithms implemented in the charger which enable to manage the EV charging load in an optimised way, with consideration of safety requirements, EV user's charging needs, operation conditions within the internal network, and requirements received from internal (Building Energy Management System) or external (grid and energy market) actors. The most important algorithms involved in power management are:

- calculation and prediction of user charging preferences (required energy, time available for charging),
- determination of EV's on-board charger characteristics (number of phases, minimum and maximum current that can be drawn by the on-board charger),
- prediction of building's total consumption/production,
- control of charging power to prevent from overload of grid connection point,
- distribution of power available for charging among charging stations in a cluster (applicable in the case several chargers are installed in the building),
- optimisation of energy delivery costs (shifting of EV charging consumption to tariffs with lower price),
- prevention of feeding the grid from local energy sources (maximisation of charging from local sources),
- control of charging load (and consequently of total building's consumption) based on DSO's or energy supplier's schedule,
- orchestration of algorithms (prioritisation between different load management target functions).

The interdependencies between individual algorithms are presented in Figure 3. The input data for operation of algorithms are provided by different actors or components (grey shaded text boxes in Figure 3): electric vehicle, EV user, Load Guard device, building owner (grid user), and external actors such as Distribution System Operator (DSO), energy supplier or Balance Responsible Party (BRP) and Building Energy Management System. The outputs of the entire group of power management algorithms are the set points or schedules of charging load for a single charger or multiple chargers installed in the building's internal network.

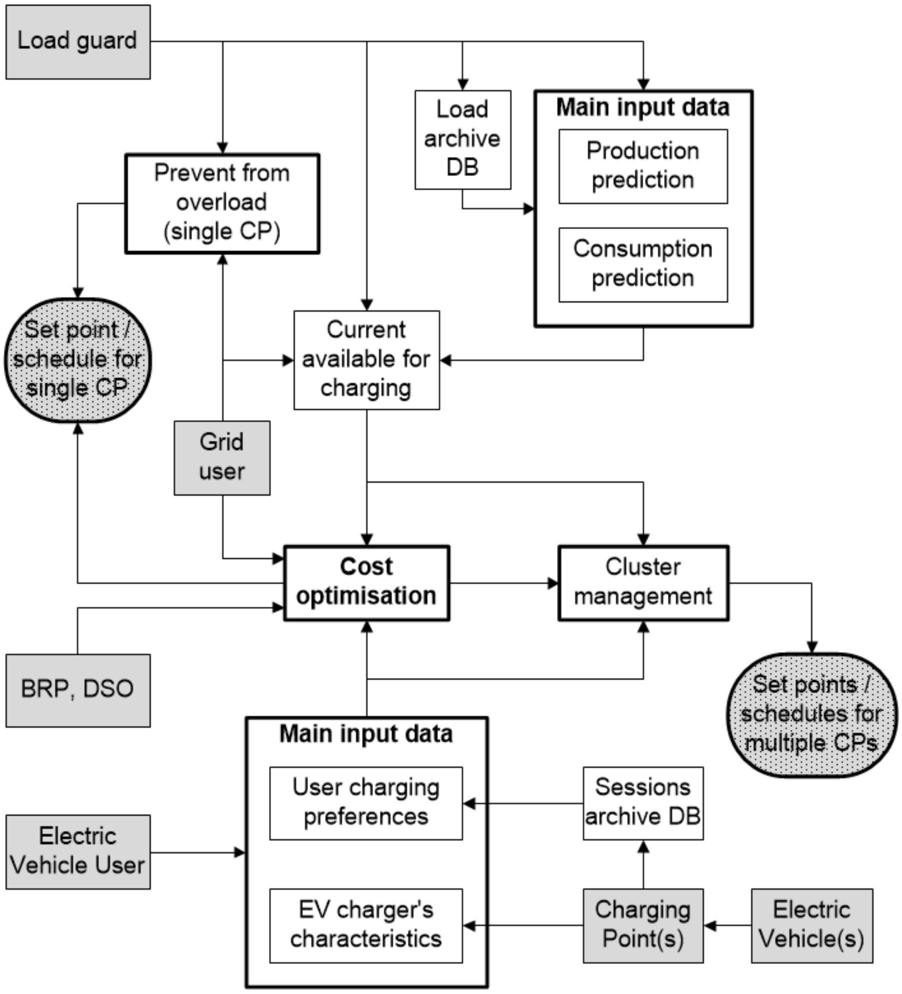

Figure 3: Power management algorithms

The algorithms can be sorted into the following main functionality groups:

- provision of main input data,
- prevention of grid connection point overload,
- cost optimisation,
- coordination of power management algorithms.

4.2 Provision of main input data

The main input data for power management algorithms are:

- EV user charging preferences,
- technical characteristics of EV on-board charger,
- predicted consumption and production in the grid user's internal network.

Information about user charging preferences (energy to be delivered, time available for charging) is used by all cost optimisation algorithms (regardless of the fact if the charging system comprises a single charger or a cluster of chargers), and by algorithm for prevention of grid connection point overload in the case of cluster of chargers).

The system enables three options for acquisition of information about charging preferences: via charger's GUI, via communication between the charger and the EV, or via charger's web interface. If any of listed methods is applied, the charger calculates by itself the estimated charging preferences. The estimation is based on statistical processing of archived data about charging sessions.

Technical characteristics of EV on-board charger can be inserted via charger's web interface or acquired via communication between the charger and the EV. If any of listed methods is applied, the charger determines the required characteristics based on measurements of currents drawn by the EV.

Prediction of building's consumption/production (i.e. the total load of all appliances in exception of EV charging load) is calculated from building energy data received from the Load Guard device. Initial daily prediction patterns are calculated once per week (for each day type of the week, for every 15-minutes interval in a day and for each phase) and continuously modified according to real-time values received from Load Guard device.

4.3 Prevention from grid connection point overload

The basic EV charging load control scenario is to prevent the grid connection point to be overloaded due to EV charging. To enable this control function, the load at grid connection point is measured by the Load Guard device which communicates the measured values to the charger. When the user connects EV to charger, and prior to beginning of charging, the charger determines the current available for charging as the difference between the rated current of main fuse (reduced by a safety margin that can be set by the user via charger's web interface) and the last measurement received from Load Guard device.

The calculated current available for charging is processed by the cost optimisation algorithms which determine the charging schedule for the newly connected EV. If cost optimization algorithms are not implemented, the calculated value of current available for charging is communicated to EV as a charging load set point to enable the fastest possible charging of EV.

Since the charger is a part of an internal network, the consumption of other consumers in the network may vary during charging, which results in modification of total load at grid connection point. The charger continuously monitors this load via Load Guard device and appropriately adapts the charging load to actual current available for charging.

4.4 Cost optimisation algorithms

EV charging costs depend on the cost of energy supplied (with associated grid fees if this is the case – depends on national regulations). If generation units are connected to the internal grid, an indirect financial loss can occur for the grid user / EV owner when the generation exceeds production and the energy is fed to the grid (and must be later bought back for higher price when the consumption exceeds the generation). Additional benefits can be gained when an agreement is reached with grid and energy actors to adapt the EV charging load to their needs (and to receive appropriate remuneration).

The intention of EV owners is therefore:

- to shift EV charging to the periods of low energy delivery tariffs,
- to use as the highest amount of energy from local sources (e.g. solar production) for EV charging,
- to adapt the charging load to the needs of Distribution System Operator or other external actors.

In all cost optimisation algorithms, the data about user charging preferences, EV on-board charger characteristics and consumption/production predictions are involved.

The algorithm for shifting the EV charging to the periods of low energy delivery tariffs calculates the current available for charging for each 15-minutes time period for the next 24 hours. Calculation is based on prediction of building's consumption/production. In the final optimisation phase the algorithm determines, for each 15-minutes period, the charging schedule in the way that the charging load doesn't exceed the power available for charging, the energy required by EV user is delivered within time available for charging, and the highest possible amount of energy is delivered to EV during the periods of low energy delivery tariffs.

The algorithm for optimisation of using the energy from local sources schedules the EV charging load in the way that the sum of planned charging load and predicted consumption of other appliances in the internal grid always exceeds the predicted production. After calculation of cost optimized charging schedules the algorithm checks if local production in any time period exceeds the total building's consumption (including EV charging), meaning that in these periods the energy would be fed into the grid. The EV charging load schedules are recalculated in the way that EV charging is shifted to periods when feeding the grid is expected.

The execution of algorithm for adaptation of charging load to the needs of external actors begins with calculation of baseline charging schedule and load flexibility margins. Flexibility margins are communicated to external actor which may require the modification of charging schedule (within flexibility margins). In this case, the charging system follows the required schedule received from external actor and re-triggers the load optimisation process.

4.5 Coordination of power management algorithms

Several power management algorithms may run simultaneously on the charger; therefore, their operation must be properly coordinated. The orchestration of power management algorithms is taken over by a special module that triggers the individual algorithms when needed and takes care that the priority levels (safety, cost optimisation, load schedules received from external actors) are considered at determination of final load set points and schedules. In determination of current charging load set points and charging load schedules, the following merit order of target function is considered:

- prevent from overload of grid connection point,
- charge according to BEMS/DSO/BRP schedule,
- consume locally produced energy,
- optimise charging based on energy delivery price.

5 Application of INCH charging system

The INCH EV charging solution can be applied in different more or less complex scenarios:

- with or without Load Guard device for measurement of load of grid connection point,
- standalone or clustered chargers, individual or shared use of charger(s),
- independent operation of charging system, or within Home/Building Energy Management System,
- operation of charging system in grid user's network which comprises local production units,
- independent control of building's load or control according to requirements of DSO or energy supplier.

The possible implementation scenarios and a variety of algorithms enable the EV user to charge its EV without being exposed to the risk of grid connection point overload, to adapt its consumption to energy delivery prices and production of local sources, and to gain additional benefits from supporting the grid and energy market actors in their daily operation.

References

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Authors

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