Intelligent Electric Vehicle Charging Controller

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***Abstract*—For domestic consumers, electricity tariffs usually have two components: one is related to the maximum available current/total power (billed in €/day) and the other concerns to the energy consumption (€/kWh). The main switchboard current is usually limited, according to the contracted power level, by way of automatic switches. To avoid main switchboard tripping by current limit violation, Electric Vehicle (EV) owners may decide to increase their contracted power (and the energy bill) or to adopt charging strategies that limit the global consumption (EV plus house needs) to the contracted current/power. In this paper, an Intelligent Electric Vehicle Charging Controller (IEVCC), allowing to use the contracted power to the maximum extent, is presented. A set of user configurable parameters can be used to define the controller behavior, in order to prevent a full switch-off. Two versions are described: a single user version that can be used at private houses and a mesh version that can be used in multi apartment buildings, providing information about consumed energy, time of use, costs and past bills.**

***Index Terms*—EVSE, Electric Vehicles, Intelligent Charging, Home Consumption, Load Management.**

I. Introduction

The number of EV users is increasing all over the world. Be it by the low value of Total Cost Ownership (TCO), low cost per km, environment reasons or government carbon taxes, the fact is that EV sales keep increasing from year to year [1], [2]. As the number of EV users increases, the need for charging points also increases. Residential building's electric infrastructure was not designed for large consumption, and usually only a normal 16A Schuko plug is available in each particular car parking place. By thermal and security reasons, the maximum recommended current is only 10A and, then, the charging capacity becomes very limited. Most manufacturers are increasing the capacity of their batteries, to improve the autonomy of EV. The charging time, for 10-16A connections, will increase to unacceptable values. Then, modern EV, equipped with larger capacity batteries requiring up to 32A per phase, cannot be charged, at all, or, if the charge is possible, then the low current makes the charging process to extend by several hours.

Residential buildings, where multiple families share some common spaces, are usually unprepared to install high current-level charging devices. If a dedicated cable is connected directly to the building's main electrical board, higher charging currents (up to the main board design capacity) can be used. Some manufacturers offer wall box chargers that allow charging at a higher current rate. Those pieces of equipment usually have a fixed charging power, which is frequently set very close to the house's maximum contracted current/power. If the EV charging current is high and other loads are connected, a tripping order may be triggered, and the complete installation will be switched off. Priority can be defined for the charging process or non-EV loads, executing load shedding plans, or limiting the EV charging rate to the maximum available capacity, which corresponds to the contracted power minus the total non-EV power in use.

A smart EVSE project is presented in [3], however, it is not clear from the document what is the smart part of the system and how it is performed or where it applies. A Stackelberg game model is used in decentralized electric vehicle supply equipment in [4]. Here renewable energies are used to charge the vehicles, and vehicle to grid (V2G) is considered.

Although there are several adjustable EVSE in the market, most of them only allow to manually adjust the charging power, according to 4 of 5 predefined set points, adjusting the maximum current that the vehicle can draw from the network. This paper presents an intelligent electric vehicle charger controller capable of auto-adjusting the charging power (current) based on a set of parameters, namely, the standing charge, the house consumption, and renewable energy production. This process is defined for the signal present at one pin on the socket on the SAE J1772 standard [5].

This paper is organized as follows: after this Introduction, the IEVCC is described in Section II. In Section III the experimental results are shown, and the Conclusions are presented in Section IV.

II. Intelligent Electric Vehicle Charging Controller

This work describes two versions of IEVCC systems, namely a Standalone version and a Mesh version. This IEVCC is built on an ESP board. Both versions allow communications over a wireless network to provide information about the charging status and receive information from the main system. The ESP32-POE supports an Ethernet network, which can be used when the building is equipped with this type of infrastructure. The choice of these two boards allows the development of low-cost systems, enabling the users' fast adoption.

The systems presented in this paper implement the open standard in the industry (OCPP [6]–[8]) that enable charging points to communicate with a central system. Public chargers commonly use the OCPP protocol. Since one of the project's objectives is to foster the development of a network of public or private chargers, it was decided to profit from the capabilities of OCPP and implement it on both versions.

A. Standalone Version

The standalone version targets a single-user environment (personal use) where the user has his private parking spot with charging energy provided from his house electric access point. This version works in Intelligent mode by looking at the house consumption and adjust the charging current according to the house consumption. It also has the advantage of work on demand (manual mode), where the user can connect it to a wall socket and define the charging current manually. This last mode makes it portable and independent from any system reading the house consumption. Fig. 1 shows a diagram of the system, which is composed by the:

- Consumption monitor hardware (a);
- Consumption monitor system - broker (b);
- Intelligent Electric Vehicle Charging Controller (c);
- Communications infrastructure;

The consumption monitor hardware is a system that monitors the power consumption of the house/building by measuring the Voltage, Current and Active Power at a timed interval. It is built using a PZEM-004T V3.0 board, based on the Vango V98xx IC [9]. The measured values are sent to the consumption monitor system that stores them on a database, allowing the user to retrieve information about

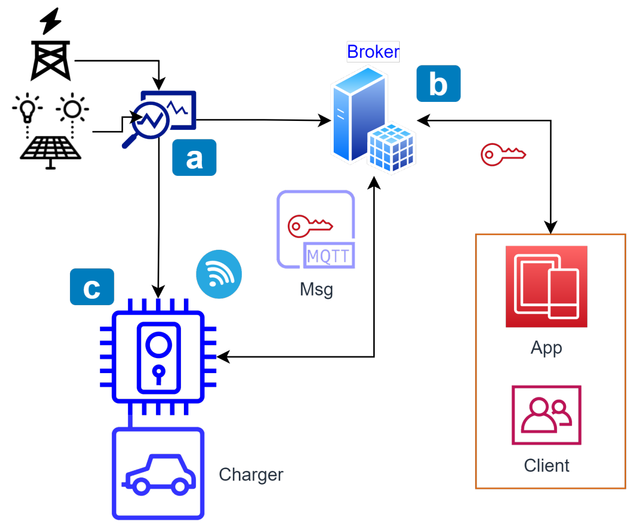

Fig. 1. Diagram of the Standalone Version.

the electricity costs of different home devices. The current information is also sent by MQTTS [10] protocol to a broker so that the IEVCC can adjust the charging current based on pre-configured information about the contracted power. The system also allows taking advantage of renewable sources when they are present (*e.g.*, solar panels), sending only the available power from these sources to the charger instead of being injected on the grid.

B. Mesh Version

The Mesh version aims to be used in condominiums, where the users do not have a garage spot with energy provided from their fraction. This version can be provided to the condominium administration and installed by a certified company or an EV charging network operator. Fig. 2 shows a diagram of the system, which is composed by the:

- Consumption monitor hardware (a);
- Broker (b);
- Intelligent Electric Vehicle Charging Controller + monitor energy meter (c);
- Communications infrastructure;

Although being very similar to the standalone, the operation of the mesh version must deal with multiple users, possibly with different needs or rights, as well as with different infrastructure conditioning factors, like cable thermal limits or maximum available power from the energy provider. Then, the loading balance process is more challenging.

Furthermore, other challenges are to decide which user has the right to more power or if all users can charge simultaneously. In order to charge, all users will have an NFC [11] card that will activate the charger. This card will identify the user on the system, where an account defines the grants access he has (maximum power he can charge, priority over other users, etc.). Based on the user profile, the number of users charging at each moment, and the available power, the system performs adjustments to all chargers, and in the worst scenario,

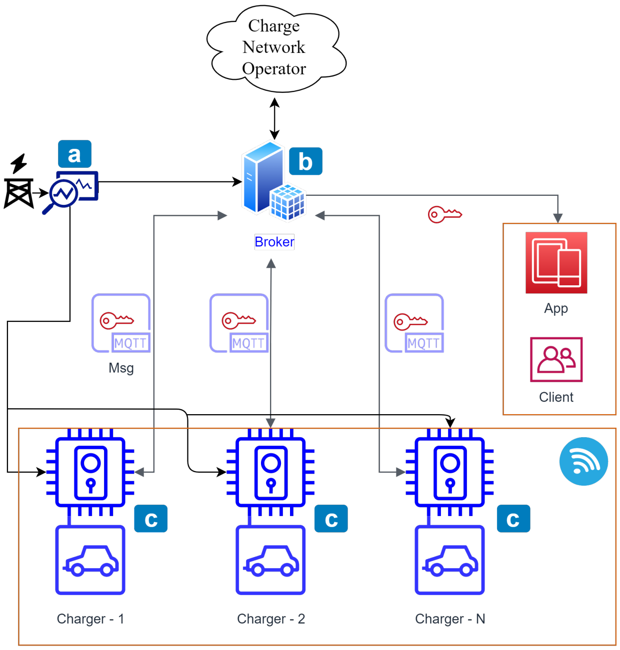

Fig. 2. Diagram of the Mesh Version.

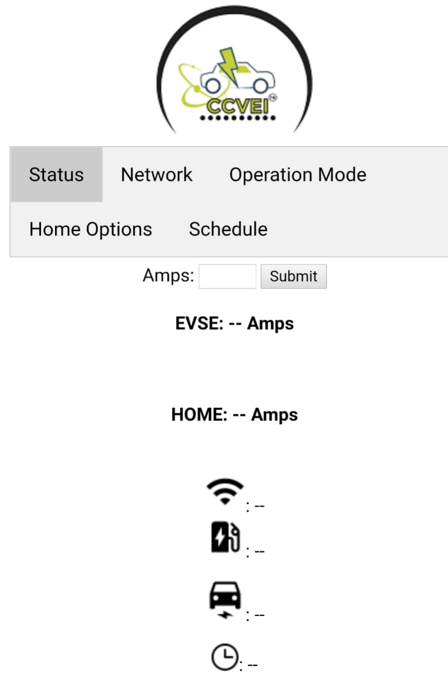

Fig. 3. IECCV Status

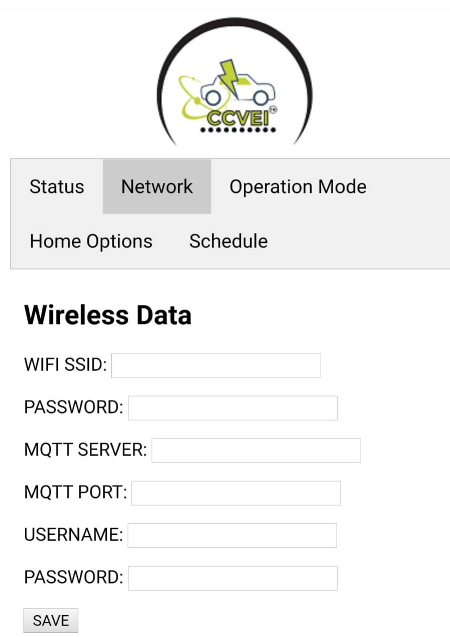

Fig. 4. IEVCC Network Configuration webpage

the user may not be authorized to charge. The chargers must communicate to the broker all information about the charging sessions (usage time, used energy) to apply charging fees.

C. Standalone user interface

In this version, the installation is simple. The first time the user connects the IEVCC to the power, the system acts as an Access Point, with a network SSID "CCVEI" (Portuguese acronym for IEVCC). The user can connect to this network using a mobile phone or a computer.

After connecting to it, it can access the configuration pages on a predefined IP address. When it does so, it is presented with the web page shown in Fig. 3, where several fields can be seen, such as:

- Amps: Here the user can set the charging current when using the IEVCC outside his home or if it wants to use the IEVCC in a normal mode.
- EVSE: – Amps. Here the actual charging current value is shown, be it in the normal mode, or the intelligent mode.
- HOME: – AMPS. The actual house instantaneous current consumption is shown. This value is received from the consumption monitor system by MQTTS.
- A set of icons that give information about the wi-fi connection status, the EVSE status, the operating mode, and if a schedule timer is active.

The next tab (Fig. 4) allows the user to configure items related to the home user wifi network and MQTT server parameters.

Only after the user configures these items, the IEVCC can enter the intelligent mode and adjust the charging current automatically.

In "Operation Mode" tab (Fig. 5) the user can select between two options:

- Intelligent mode: in this mode, the IEVCC adjusts the charging current (power) based on the home consumption and the contracted power.
- Manual mode: in this mode, the IEVCC operates at a fixed charging current (power) set by the user.

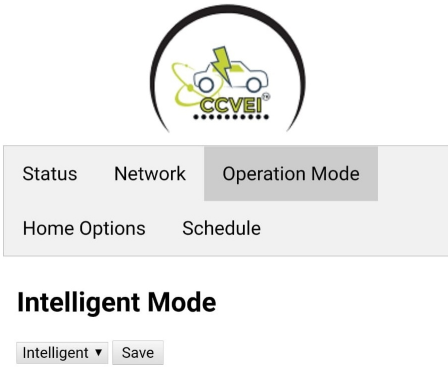

Fig. 5. IEVCC Operation Mode webpage

The Home Options tab (Fig. 6) is where the user can set the contracted power.

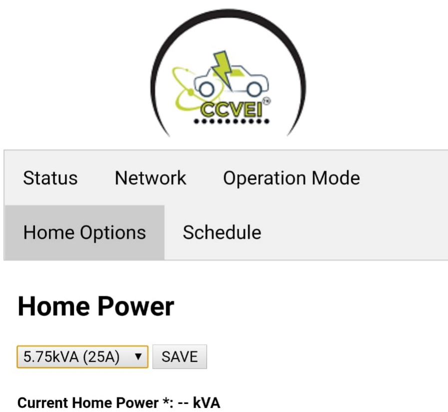

Fig. 6. Home Options tab

III. Experimental Results

A series of tests were performed, including a full charge session. All these tests were carried out in a real environment, in which the parking spot has an available plug with energy provided directly from the apartment and while the residents continued performing their typical tasks (*e.g.*, cooking, turning on washing machines) without any restrictions. The IEVCC has dynamically adapted the available power for charging without the need for human intervention.

Fig. 7 shows the full charging session (from 33% up to 100%) of an electric vehicle (a 2015 24 kWh Nissan Leaf) using a first version of the standalone IEVCC. In this case, the user has a contracted power of 5.75 kVA, equivalent to a maximum current of 25 A. In this house (and today, in many houses in Portugal), the installed meter is an intelligent version that cuts off the power much faster than a Residual Current Breaker with Over-Current (RCBO) in case the current equivalent to the contracted power is overpassed. Thus, a 3 A buffer was defined to avoid total house current to overpass the defined cut current on the intelligent meter.

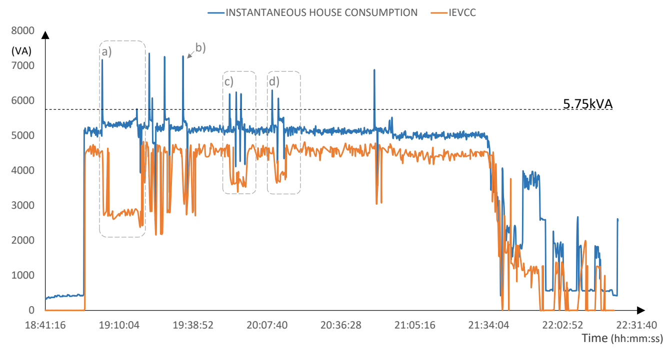

Fig. 7. Charging session data

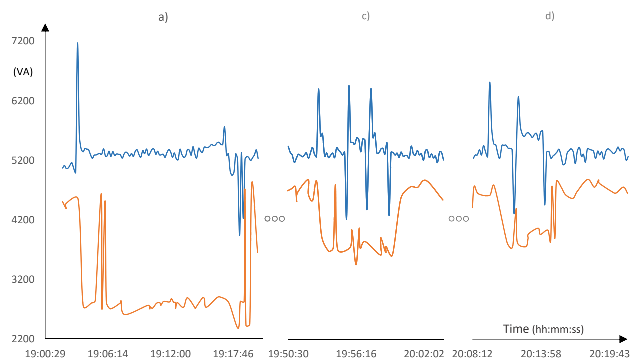

Fig. 8. Charging session data details of Fig. 7

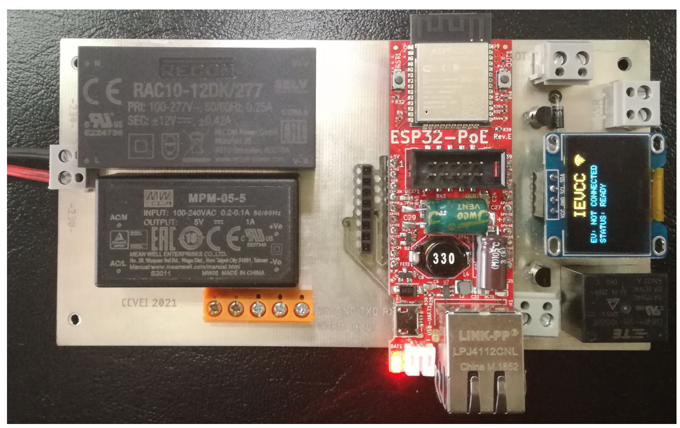

Fig. 9. Prototype of the IEVCC

Whenever the instantaneous consumption of the house exceeds the limit value, the IEVCC automatically adjusts the charging current (which is related to the charging power) so that the sum of the current drained by home appliances working at that time and the vehicle does not exceed the maximum defined value. It is possible to see in the graph that the established value is momentarily exceeded although immediately corrected (moment a, b, c and d in Fig. 7). A zoom of some of these segments are presented in Fig. 8. Here, it is well visible the moments where this peak occurs. These peaks may happen because an appliance in the house was turned on and requested enough current so that the total current drawn exceeds the maximum allowed. Since the consumption monitor system does not measure the values in real-time, there is always a tiny delay leading to a rapid consumption increase. When the consumption monitor system makes a new measure, it instantly sends this new value to the IEVCC, which immediately intervenes, lowering the charging current available to the electric vehicle. In a more extreme case, the IEVCC can interrupt the EV charging process until the available power is sufficient to continue the charging session (reference to J1772 standard). It should be noticed that although the intelligent meter at the home user is faster than the RCBO, it is not also a real-time process, so the delay that our system takes to act is not significant enough for the intelligent meter to cut the current.

Fig. 9 shows a version of the prototype developed, and used in the tests, which was built in-house at ISEC.

IV. Conclusions

In this work, an Intelligent Electric Vehicle Charging Control able to dynamically adapt the vehicle charging current based on a set of parameters was presented. This system is not limited to work in this mode and can act as a simply EVSE, when used on travels. Two versions of the IEVCC were described, and the results for the standalone version were presented and discussed. The Mesh version is in its final development phase, and the authors expect to present results from this version in the near future. As future work, the introduction of AI is being considered so that the IEVCC can predict when to act based on historical values and react instantaneously. This version could also overcome potential intermittent connection problems between the home consumption monitor system and the IEVCC.

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