Comparison of electric vehicle charging efficiency with IEVCC and a typical EVSE

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Abstract

More than a fashion trend, EVs (Electric Vehicles) are here to stay and present themselves as a solution for combating climate change. In addition to the TCO (Total Cost Ownership) reductions, these vehicles are much more efficient than their equivalent ICE (Internal Combustion Engine) counterparts. Even if all the energy used to charge an EV comes from renewable sources, one of the points in the energy transfer chain, where efficiency can be optimized is in the charging process, whose efficiency depends on the charging power. This results from the fact that the EV internal charger has a fixed minimum power consumption to operate. Charging with a higher power results in less time charging, so less time is spent wasting energy on the EV internal charger. EVs come equipped with an internal charger whose charging power can be controlled by an external charge controller, commonly known as an EVSE (Electric Vehicle Supply Equipment). Manufacturers typically supply EVSEs with a fixed charging power setting, so they can be used on a household plug without any safety issues concerns. Usually, this power is set to around 2.3 kW for 230 V, but it is not uncommon to find values around 1.84 kW and very rarely 2.76 kW (which corresponds to currents of 8~12A). Often these EVSEs, due to the low charging power, do not always allow the users to restore the total charge used on a common day. In addition, the use of energy in a house is conditioned by the contracted power, which, if exceeded, triggers the main switchboard of the house. This requires some scheduling to manage an EV charging session in conjunction with other house appliances usage. The use of an EVSE that considers the instantaneous house consumption and adjusts the EV charging to the maximum available power, allows to maximize the charging efficiency. A new EVSE that implements these functionalities has been developed and is addressed in this work. This EVSE, which is called IEVCC (Intelligent Electric Vehicle Charger Controller) is compared with a fixed EVSE, and the results show greater efficiency in the charging process.

Introduction

Climate change and its association with the production of greenhouse gases are undeniable. The use of emission-free vehicles can partially mitigate the problem. The European Commission adopted on 14 July 2021 legislative proposals setting out how it intends to achieve climate neutrality by 2050, including the intermediate target of at least 55 % net reduction in greenhouse gas emissions by 2030 (EC, 2021). EVs (Electric Vehicles) can be two to four times more efficient than vehicles with internal combustion engines. Additionally, if clean renewable energy sources are used to charge EVs, it is possible to reduce the dependence on oil-based fuels, and it is also possible to ensure significant reductions in greenhouse gas emissions. The increased efficiency and the pollution reduction issues are producing a strong momentum in electric vehicle markets despite the pandemic scenario of the last two years. Towards a climate plan which seeks to consistently reduce the carbon life cycle footprint per car, several car makers are setting objectives of becoming fully electric car producers in the horizon of 2030–2035 (International Energy Agency, 2021).

The sales of electric light-duty vehicles translate to estimated cumulative sales of 55–73 million by 2025 (International Energy Agency, 2021). EV sales are on continuous growth, and to boost the acquisition of EVs in the EU, several members offer some form of tax benefits and or purchase incentives to stimulate the EV market (European Automobile Manufacturers' Association, 2021). In this context, it is extremely important that EVs and their charging infrastructure are as efficient as possible. There are two distinct scenarios when using an EV: during use and during charge. While the first concern arises when using the vehicle, efficiency during recharging is just as important, since there are always losses in the charging process. Efficiency, in this case, can be defined by the percentage of energy stored in the battery in relation to the total energy withdrawn from the grid. The charging process depends on multiple factors such as ambient air temperature, battery charge level, supply voltage used to charge the vehicle, and others. Brooks (2021) states that charging efficiency can range between 70 and 90 %.

The EV-EVSE charging efficiency is voltage level dependent. Level 1 equipment operates at 120 V and Level 2 at 240 V. Studies were carried out to compare the efficiency of the two systems in a set of 115 charges, with a mean charging efficiency of 85.7 % and on average, Level 2 charging was 5.6 % more efficient than Level 1 (Sears et al., 2014). When it is necessary to use energy to acclimatize the battery during the charging process, efficiency is also reduced. This work also suggests that efficiency gains may be greater in charging stations, where charging times tend to be shorter rather than longer residential charging. The time taken in the charging process is related to charging efficiency, derived from the fact that an EV charger presents an efficiency that grows with the transferred energy in a shorter charging time interval (Gautam et al., 2011). The available charging power in a house is conditioned by the contracted power. This limitation conditions the EV charging sessions scheduling to manage the charge power in conjunction with other house appliances usage. The use of an EVSE that considers the instantaneous house consumption and adjusts the EV charging to the maximum available power allows maximizing charge efficiency. This paper presents an intelligent EVSE that by maximizing the charging power in function of the available power and house instantaneous consumption, can increase the efficiency of the charging process. The remaining of this paper presents the IEVCC, the experimental results and the conclusions.

Intelligent Electric Vehicle Charging Controller

The IEVCC (Intelligent Electric Vehicle Charging Controller) is an EVSE with the ability to adjust the charging current of an electric vehicle based on a set of parameters *(e.g.,* house maximum available power, house instantaneous consumption, renewable production, etc. (Cardoso et al., 2021). Comparison of IEVCC features with market related systems is out of scope in this work. Currently, in IEVCC development, there are two versions of the intelligent charger controller: standalone and mesh version. The standalone version was developed for private users (personal use), where the user has his private parking spot with energy provided from his house, and the mesh version is targeted for public use or multi-user, such as a condominium where there are no private parking spaces with energy provided from the home user. This work focus is on the standalone version and all results presented are based on this version. This IEVCC is built on an ESP-32 board, which allows communications over a wireless network that provide information about the charging status and receive information from the main system. Choosing these boards allows the development of low-cost systems, enabling the users' fast adoption.

A diagram of the standalone version is presented in Figure 1. The system is composed of the following components that allow it to work in an intelligent mode (where the charging current is adjusted according to the house consumption and the renewable production, when present):

- 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 and the renewable production 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 (Vango Technologies, Inc., 2021). The measured values are sent to the consumption monitor system that stores these on a database. This allows the user to retrieve statistics about the total electricity costs or even from multiple home devices (if required by the house owner), renewable production usage and how much was used in the building or injected into the grid. The consumption monitor system also publishes the current values (house consumption, renewable production) on a MQTT (OASIS Open., 2019) topic, which is subscribed by the IEVCC, allowing it to adjust the charging current so that it does not exceed the maximum contacted house power or the maximum renewable production (these settings and operation modes can be adjusted in the IEVCC).

Figure 2a shows the installed version used on tests and Figure 2b presents an improved version (currently in development) of the IEVCC that allows connection to an LCD screen, a status LED and a PZEM-004T for measuring the charging power and energy used.

The IEVVC provides a home page through an embedded webserver (presented in Figure 3), where information is provided, such as the charging current, the house consumption received in the MQTT topic, the network connection status, etc. Other tabs are available that allow configuring the network parameters, Operation Mode (intelligent or manual) (Cardoso et al., 2021), MQTT server and topic to subscribe, Home Options (choose the contracted power), schedule a charge and check for updates (System Tab).

Experimental Results

The setup for the experimental results consisted of a 2015 Nissan Leaf with a battery pack of 24 kWh (with a net capacity of 22 kWh) and an on-board charger up to 6.6 kW (28 A). From this vehicle, it is known that at the time of the experiments, the real battery capacity was around 74.5 % (known as the State of Health and obtained from Leaf CAN bus) of the original capacity, which results in a net capacity of about 16.39 kWh. The

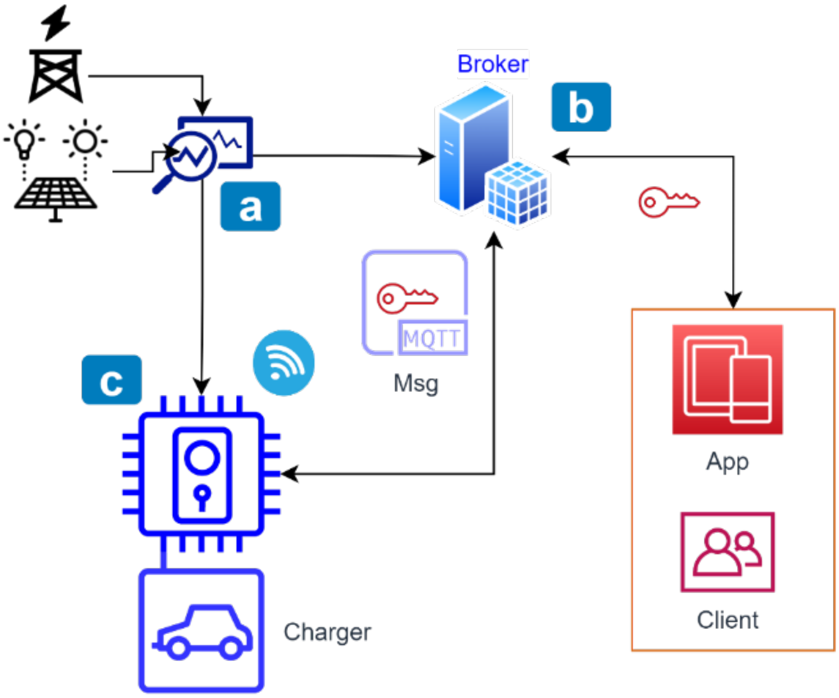


Figure 1. Diagram of the Standalone Version.

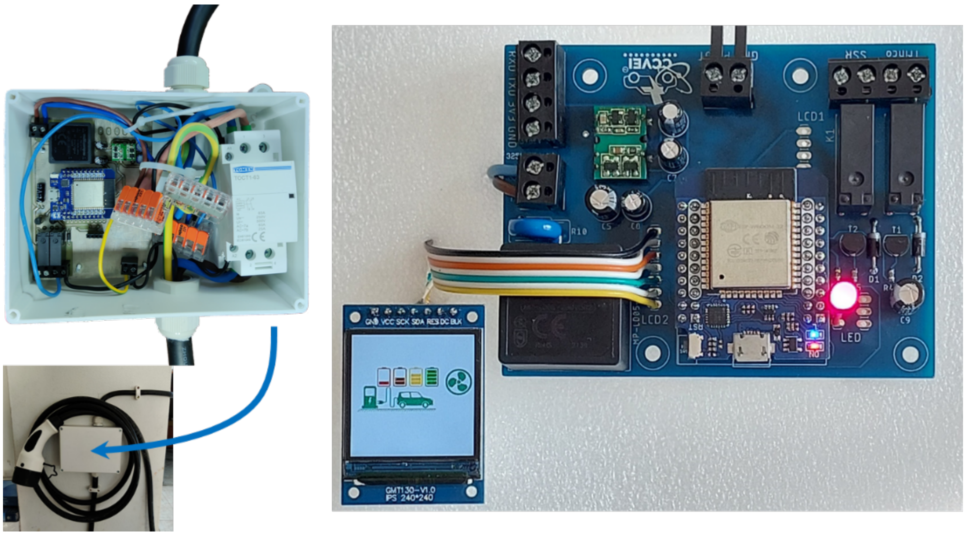


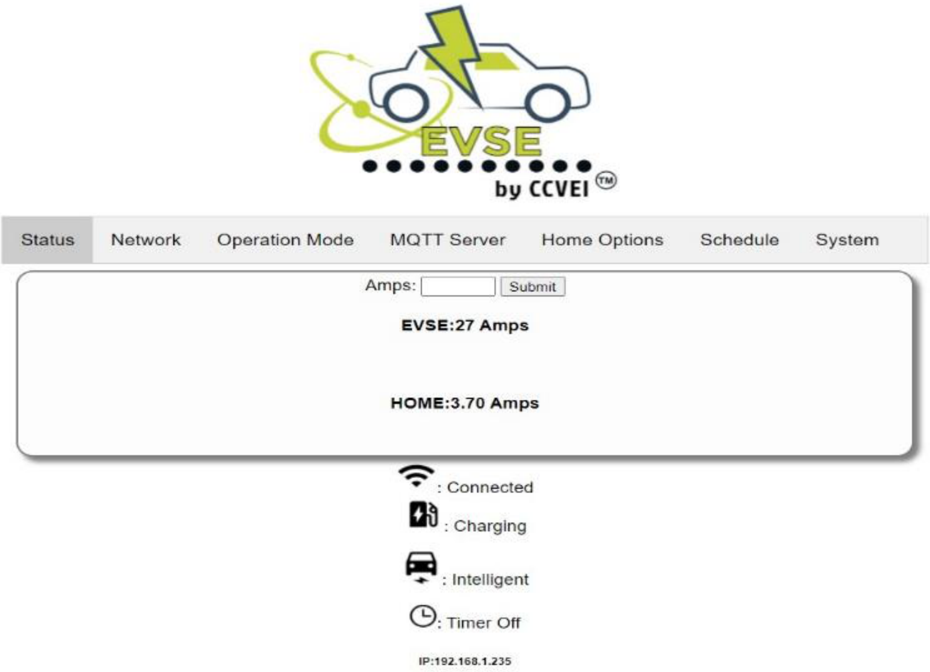
Figure 2. The IEVCC versions where the first picture shows IEVCC used in tests. The second one shows an improved version of IEVCC board.

original EVSE was available for charging this vehicle, enabling it to charge at a fixed power of 2.3 kW (10 A). The IEVCC was used for comparison, which can charge from 1.38 kW (6 A) up to 7.36 kW (32 A), but in this case limited to 5.1 kW (22 A) due to the contracted power at the EV user home (5.75 kVA, 25 A), considering a safeguard of 3 A.

Three different experiences were analysed:

- A full charge starting at 9 % battery level indicated on the leaf dashboard using the original EVSE;
- A full charge starting at 9 % battery level indicated on the leaf dashboard using the IEVCC;
- A full charge from about 8 % using the IEVCC.

For each experiment, the charging sessions are presented in Figures 4 to 6, respectively. As mentioned before, the data present in these figures respect to the vehicle power consumption measured at the charger power inlet with a PZEM-004T. For each session, the summary of results can be seen in Table 1. The first row of the table shows that for the first charging session a total of 18.224 kWh were consumed from the grid, resulting in a charging efficiency of 81.8 %. The second row of the table shows that a total of 16.576 kWh was consumed from the grid for the same amount of energy placed in the battery, which results in an efficiency of 90.0 % (charging from 9 % to 100 %), an increase of more than 8 %. Finally, the last row shows the third charging session results, where an efficiency of almost 94 % was achieved.



Amps:

EVSE:27 Amps

HOME:3.70 Amps

: Connected

: Charging

: Intelligent

: Timer Off

IP:192.168.1.235

Figure 3. IEVCC web page.

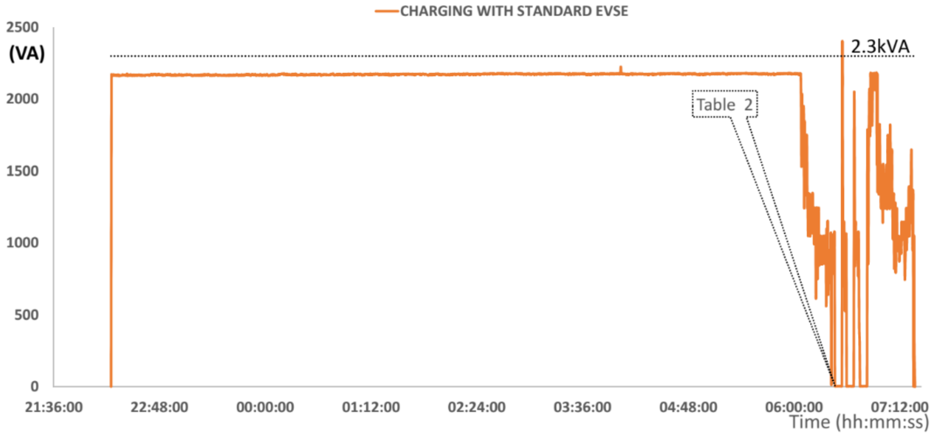


Figure 4. Charging session data with standard EVSE.

Another set of results was computed and presented in Table 2. Here the same experiments were used, but the final stage of charging was at 98% of charge (presented in the vehicle dashboard). The results show an increase in efficiency in all experiments, but the charging sessions with the IEVCC still have a higher efficiency than with the original EVSE.

The vehicle behaves the same way at the end of a full charge, presenting three charge pulses. However, these pulses are not always equal from charge to charge. All the values used in Table 2 were considered from the beginning of the charging session till this stage. After this charging point (labelled in the figures as Table 2) the remaining charge that can be stored is not relevant compared to the first charging stages (the vehicle SOC estimate is 2 %) but the time taken is about 1 hour. These facts justify the analysis presented in Table 2.

Since the two last charging sessions (presented in Figures 5 and 6) were done with the IEVCC at some points, the charging was interrupted because some of the house appliances were set in use without any restriction leading to the IEVCC act to avoid the activation of the main breaker switch. If the available current is lower than 6 A, the EV will not charge, so the graphics will present zero power delivered.

Conclusions

In this paper, a comparison between the efficiency of charging with the original EVSE of a vehicle and the developed IEVCC was made. The results show that the IEVCC presents a better charging efficiency, resulting in less loss on the charging process and energy savings. This results from the fact that the EV internal charger has a fixed power consumption. Charging with a higher power results in less time charging, leading to wasting less energy on the EV internal charger. We could argue that if the car manufacturer provided a higher power

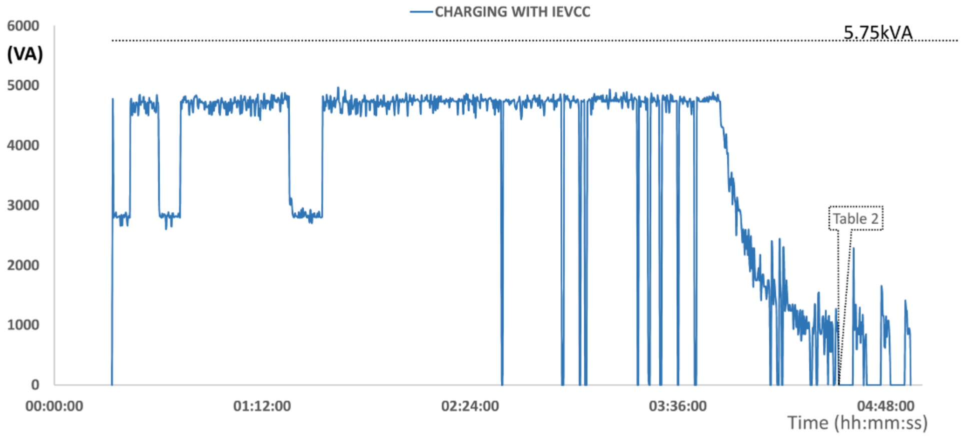


Figure 5. IEVCC charging session A data.

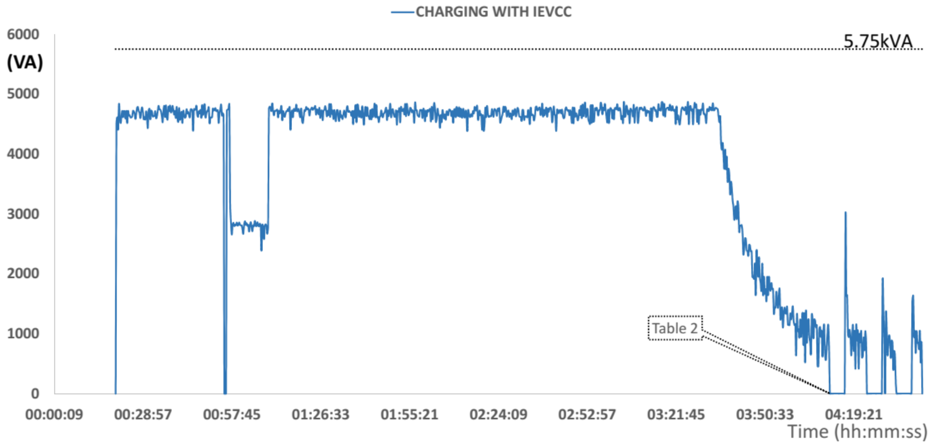


Figure 6. IEVCC charging session B data.

Table 1. Comparison of charging efficiency for a full charge (the charger cut-off).

Equipment	Total Battery Capacity (kWh)	State of Health (%)	Net Battery Capacity (kWh)	Consumed Energy (kWh)	Full Charge (%)	Average Charging Power (W)	Calculated Efficiency (%)
Standard 10A Charger	22	76.5	16.39	18.224	91	2007	81.80
IEVCC Charger - A	22	76.5	16.39	16.576	91	3603	90.0
IEVCC Charger - B	22	76.5	16.39	16.133	92	3715	93.50

Table 2. Comparison of charging efficiency until end of constant voltage phase (~98 % of SOC).

Equipment	Total Battery Capacity (kWh)	State of Health (%)	Net Battery Capacity (kWh)	Consumed Energy (kWh)	Charged Until 98% of SOC (%)	Average Charging Power (W)	Calculated Efficiency (%)
Standard 10A Charger	22	76.5	16.39	17.365	89	2124	84.0
IEVCC Charger - A	22	76.5	16.39	16004	89	4227	91.1
IEVCC Charger - B	22	76.5	16.39	15.752	90	4265	93.6

EVSE, the efficiency will also be equivalent to the IEVCC. However, this would limit the owner's usage of the remaining electrical house appliances, since there was a risk of activating the circuit breaker that limits the contracted power. With the IEVCC, such problem does not occur, because the charging power is adjusted dynamically so that the contracted power is not overtaken.

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