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Research article

E-Mobility: dynamic mono-phase loads control during charging session of electric vehicles

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Abstract: This paper presents the primary objective of a research project which aims at enhancing the world of e-mobility by highlighting the continuous evolution and demand of the Electric Vehicle (EV) in modern cities and the consequent need for more and more innovative charging systems. Here we focused on a current and incoming EV drawback, namely the variety of EV charging methods which are currently available in the market. An adaptive solution, which is suitable for both domestic and working environments, is presented, where single-phase recharging points are applied with non-high power. The task is to provide a user-friendly support for any end-user who wants to acquaintance with the EV world. Three stages are characterizing this approach: (1) the search for new solutions for the charging of electric vehicles, (2) the finalization and achievement of the proof of concept and product, (3) a set of functional tests (i.e. the validation). The proposed product is preserved from electric blackout during the EV recharging phase within a typical daily life domestic activity: this result is achieved through a combination of smart devices, an intelligent framework and the charging point. An optimized calculation program supervises this architecture and it allows the real-time interaction and communication between all the components by carrying out a dynamic control of the loads.

Keywords: electric vehicles; smart device; dynamic control; charging station

1. Introduction

At the end of the 19th century Electrical Vehicles (EVs) were introduced in big cities like New York and London: at this time, some taxis were equipped with lead batteries whose performances were well appreciated in terms of efficiency, reduced noise and pollution. The usage of electrical power was preferred for a while: after few years, thanks to the discovery of many oil fields, the combustion car became (and remained) the most adopted solutions on the mobility market for a long time. In the most recent years, however, there has been a change on this direction, especially considering the incoming marketing strategies of the biggest car manufacturers in the world. This has been pushed by the increasing problem of the pollution of our planet, which has given priority to the technological innovation and at the same time to the social conscience towards the research of more green and ecological systems. In this context, the increase of the demand for the EVs is an example [1,2].

In this context we should also notice that market is evolving not so quickly as it could be, due to the very high costs of the EVs, the not homogenous distribution of the recharging stations in the territory and the not large diffusion of some technologies. Furthermore, consumers suffer for the lack of information, generated by the confusion regarding the potentials of the EVs and the bad consciousness about the real use of their private vehicles [3,4]. Generally speaking, some critiques to the electric mobility are inherited from the perception of the short range of the Evs batteries and the difficulty to charge the vehicles out of your private house [5].

DriWe is an optimized framework which aims at resolving some of this issue by taking advantage of smart gird and wireless technology [6]: above all, the DriWe architecture want to relief the end-user from any required technological background offering an economically advantageous and user-friendly experience where the user will only focus on the benefit of the EV usage. The DriWe system proposed a set of multiple solutions, from the Photovoltaic Panels to retrofitted EV and integrated charging point (Figure 1). The system integrates, in particular, a simplified and optimized real-time monitoring architecture for the recharging of latest generation electrical cars.

2. Materials and method

2.1. The problem

The charging of EV requires the absorption of high power of electricity, especially when requiring fast charging process of modern EVs. In a domestic and middle industrial configuration, a typical drawback of the recharging process is about the possibility of a blackout of the electrical network, due to the high demand of power from the EV charging station (i.e. the charging point). Here we present the DriWe component which allow a client to avoid any blackout in a domestic place, minimarket or shop during EV single-phase charging session. We specifically focus on two keywords, namely the *blackout* and the *single-phase* charging. This work, in fact, presents a validated solution to avoid the disconnection of the electricity meter and therefore the blackout: single-phase is the considered system, since these ones are the charging points most suitable to induce a blackout, due to their low limit of the contractual powers.

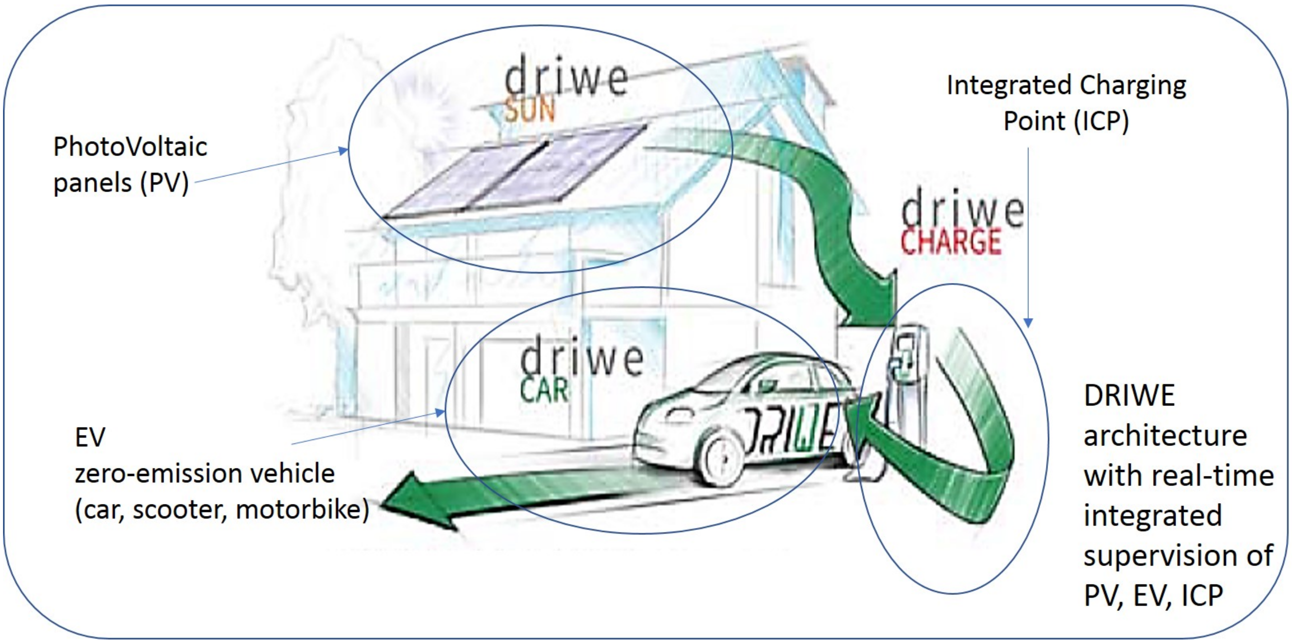

Figure 1. Interaction between the integrated different elements of the DRIWE architecture for optimized EV charging.

The demand for a solution should took into consideration the various components which are currently supplied in the market, focusing on the reliability, the functionality, the data transmission and, moreover, the costs of the smart device that has to be designed. The fundamental element of the choice is therefore the price of the device. The interposition of the smart device in the network assumes the task of evaluating the priorities of the loads and of communication to the central system. The system, in turn, should use a special OCPP (Open Charge Point Protocol) communication protocol to interface with the charging column and allow remote control and management of the parameters [2].

The reported approach and solution is the result of a market analysis of the competitors and of the research in the e-mobility field. Moreover, it diversifies from current systems which adopt different technical solutions like, for example:

(i) sending a 0–10V voltage signal from the home automation system to the charging station;

(ii) connecting between two energy meters (i.e. the first downstream of the energy meter, the second one integrated in the charging station with a data transmission via Modbus);

(iii) the connection takes place directly between the charging station and the latest generation of smart meter through a special connection port which is located in the two mans without requiring additional devices.

2.2. The components

A functional scheme can be introduced between the EV and the end-user: this functional scheme summarizes the structure of a possible network examined for charging an electric vehicle and it is reported in Figure 2. According to the scheme, the most important elements are the Smart Device, the Central System and the Charging Point. Each one of these elements had to possess specific characteristics to interact and to communicate with the other components. In particualr, the Smart device has to respect particular characteristics such as: high quality design and integration, fast communication via wirelss wi-fi commmunication protocol (IEEE 802.11); it should also have a low cost, be integrated via API, and capable to display real-time charging consumption. The Central system also reflects precise requirements such as: OCPP communication capability, real-time montioring skill, mathematical algorithm integration. The last element is the Charging Point which has to be "smart" and able to communicate via OCPP protocol [8].

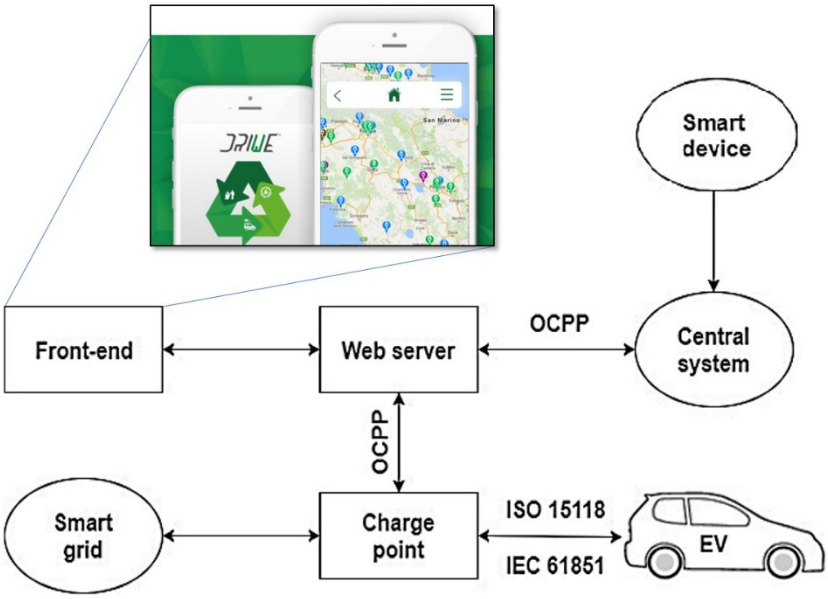

Figure 2. The main structure of the DRIWE operating scheme: on the end-user side, a mobile app allows accessing DRIWE services (and localizing geo-referenced charging points).

2.3. The real-time monitoring system

A block diagram of the system has been designed in order to detail the implementation of the monitoring program. The diagram is structured in different parts in order to allow an easy management of the process and highlights the essential requirements and performance.

First of all, the code recalls the smart device through an API (Application Programming Interface) and the DriWe central system. Then, the variables are initialized and stored for a real-time working cycle: this set of variables is updated every 10 s. Such a time stamp was chosen to prevent any possible blackout in case of an exceeding power vs. the contractual power limit. At the same time, this range of time is sufficiently high to prevent any data clogging on the communication network. The set of variables includes the single-phase voltage, the contractual power of the supply point and the current power as it is absorbed by all the loads, including the load of the charge point—see also Figure 3.

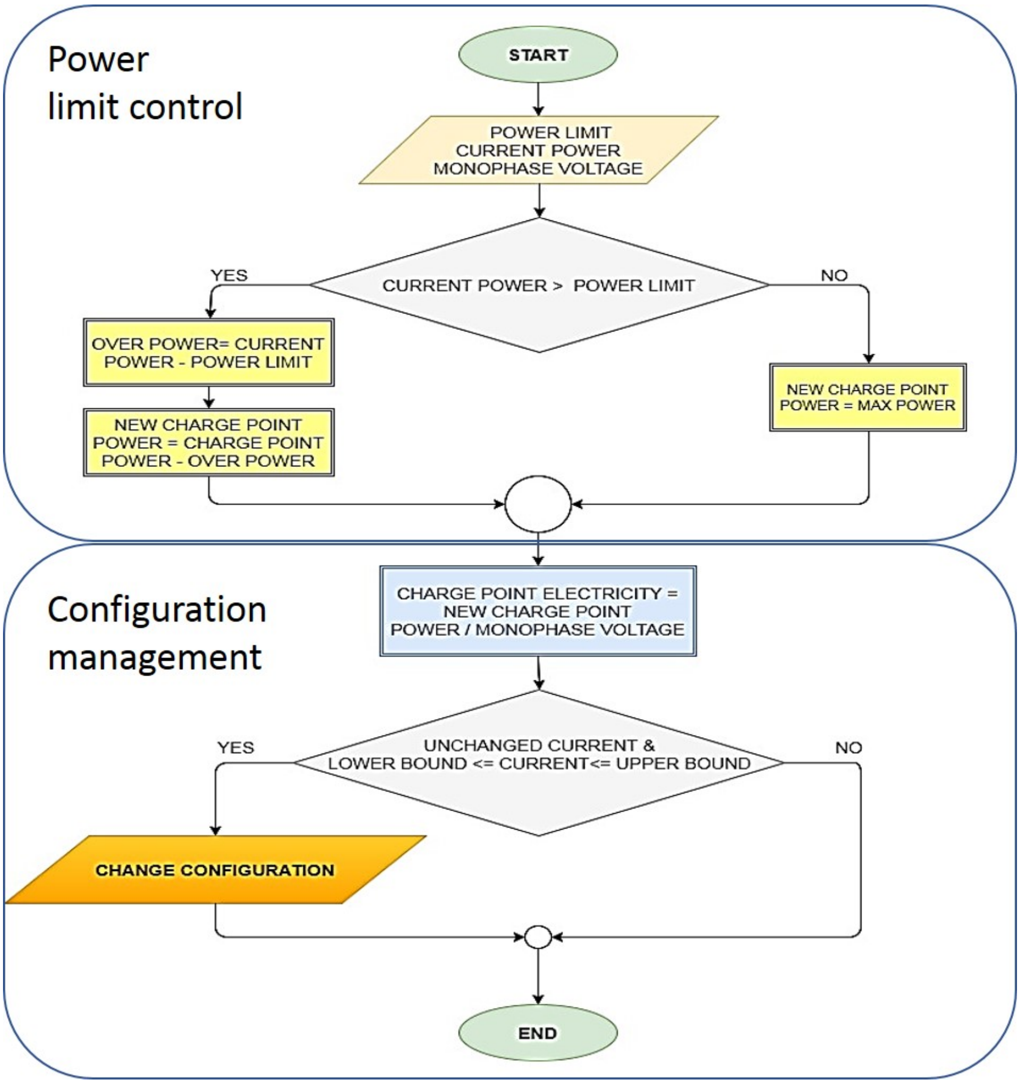

Figure 3. The flow chart of the DRIWE system and real-time monitoring program.

According to the scheme of Figure 3, the code then allows to control the instantaneous absorbed power. At this stage, two possible events may be triggered are represented, according to the following condition: is the instantaneous power absorbed by the loads greater than the contractual power limit? The conditional statement can cause the following two actions:

• YES flag—it is occurring an excess of power, which will be subtracted from the supplied power by the charging point in order to return within the contractual limits and avoid any possible electric blackout

• NO flag—namely the power supplied which is provided can be maximized

Therefore, both the options allow the calculation of the new optimal value of the power which will be supplied by the charging point. Nevertheless, it is important to notice that the value of the current has some constraints in term of limits: the lower limit is defined from the CEI EN 61851-1 regulatory duty cycle, whereas the upper limit is given by the characteristics and specifications of the individual charging points (i.e. 16 A for a charging station of 3,7 kW and 32 A for a charging point of

7,4 kW). Thus, the program allows changing the value of the current whether the novel value is different or equal to the previous one. The modification of this parameter takes place through a command which is called *Change Configuration* within the diagram (Figure 3).

3. Results

Different charging experiments and trials were performed at the DriWe laboratory centre with three different types cars or EVs, namely a Renault Twizy, a retrofitted-electric 500e and a Nissan Leaf. The recharging process was performed via a single DriWe charging point. Table 1 reports the main properties of the used connectors and the tested EVs, according to the aforementioned EVs.

Table 1. Main characteristic of the charging point connectors vs. the different models of the tested EVs.

EV model	Capacity [kWh]	Mode	Type	Max charging power [kW]
REANULT Twizy	6,1	2	3 A	2,3
500e	26	2	3 A	3,7
NISSAN Leaf	30	2	1	7,4
	30	4	CHAdeMO	50

The tests were performed by monitoring the cars for an estimated time of 5 hours. In this way a partial or complete recharge of the vehicle is carried out during a normal working day and therefore with variations in the loads present in the laboratory.

RENAULT Twizy and 500e—as it is shown in Figure 5, the graph presents three different zones called A, B and C, respectively, which represent the power absorbed by the loads as tested in the laboratory vs. the time, expressed in [W] and [s], respectively:

- Zone A: load monitoring (PC, light bulbs) in the preliminary phase.
- Zone B: connection of the EV to the charge point with consequent start of the recharge and instantaneous increase of the absorbed power. The consequent introduction of an electric load gives an exponential increase in the power absorbed by the loads (blue line refers to the absorbed power of the vehicle plus the power as it was absorbed by the equipment), with exceeding the contract power (i.e. red line in the graph) simulated to 3 kW. Here we have adopted a 3 kW value to test the operation in the most difficult conditions for the system, since this value represents the current contractual power limit in some of the EU countries, even if it is difficult for those who buy an EV to maintain this level of power. However, a different value of the contractual power limit can be set-up in our system, according to the application and the rules of the country where the system will be installed. At this stage it occurs a prompt timely intervention of the calculation program which allows the variation of the current and of the power parameters, thanks to the *change configuration*

command (see the configuration management block in Figure 3).

- Zone C: during this phase, a repeated set of power peaks occur, due to the activation of the recharging operation. At each further event of power peaks, an automatic and real-time reduction is performed.

The recharging session with the power management was not successful because of the connection between the EV and the charging station which was not allowing a proper modulation of the signal and of the current: this device, in fact, was not equipped with an Electric Vehicle Supply Equipment (EVSE) and the Pulse With Modulation (PWM) control.

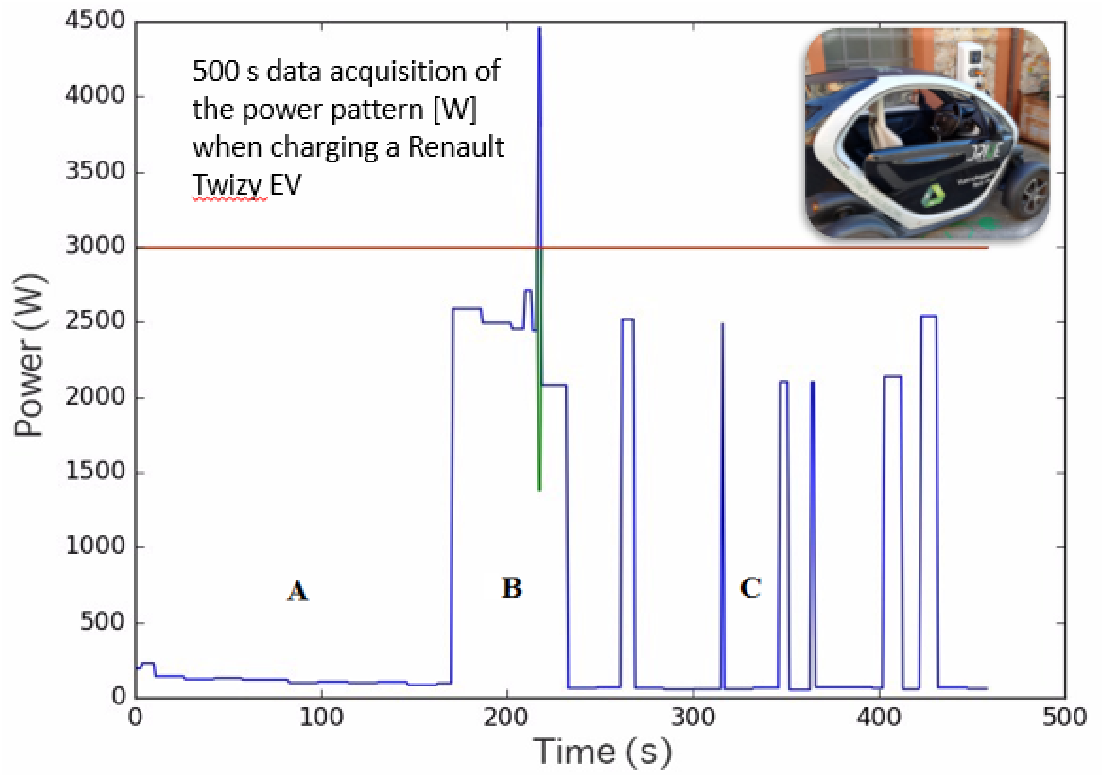

Figure 4. Time pattern of the applied power during the laboratory experiment with the Renault Twizy EV (blue line: instantaneous absorbed power; green line: maximum power of charge point; red line: threshold value). Similar pattern were observed when performing the experiment with the 500e.

NISSAN Leaf—the plots and graphs of Figure 5 are representative of the observed patterns when charging the Nissan Leaf EV. Compared to the previous ones (Figure 4), it can be noticed that these latter plots are quite different. We can distinguish:

(i) red line: this line shows the contractual power limit which was set at 4.5 kW for this test

(ii) yellow line: this is the instantaneous absorbed power (i.e. the power of the charging point plus the one of the loads

(iii)blue line: the power of the loads from the environment

(iv) green line: the maximum value or threshold which was available for the recharging process.

The graph of Figure 5 has been divided into three parts in order to facilitate the comprehension of the occurring events. Starting from the central portion—i.e. the part B—it can be noticed that the line of the instantaneous absorbed power is promptly following the red line. This happens thanks to the real-time correction of the monitoring program which allows adapting the value of power, based on the variation of the loads in the environment; because of that, the current output from the charging point is also modulated. In this portion of the graph an optimal recharge session of the vehicle occurs, since the charging current is preserved within the lower and superior limit preset by the monitoring system, allowing the current modulation.

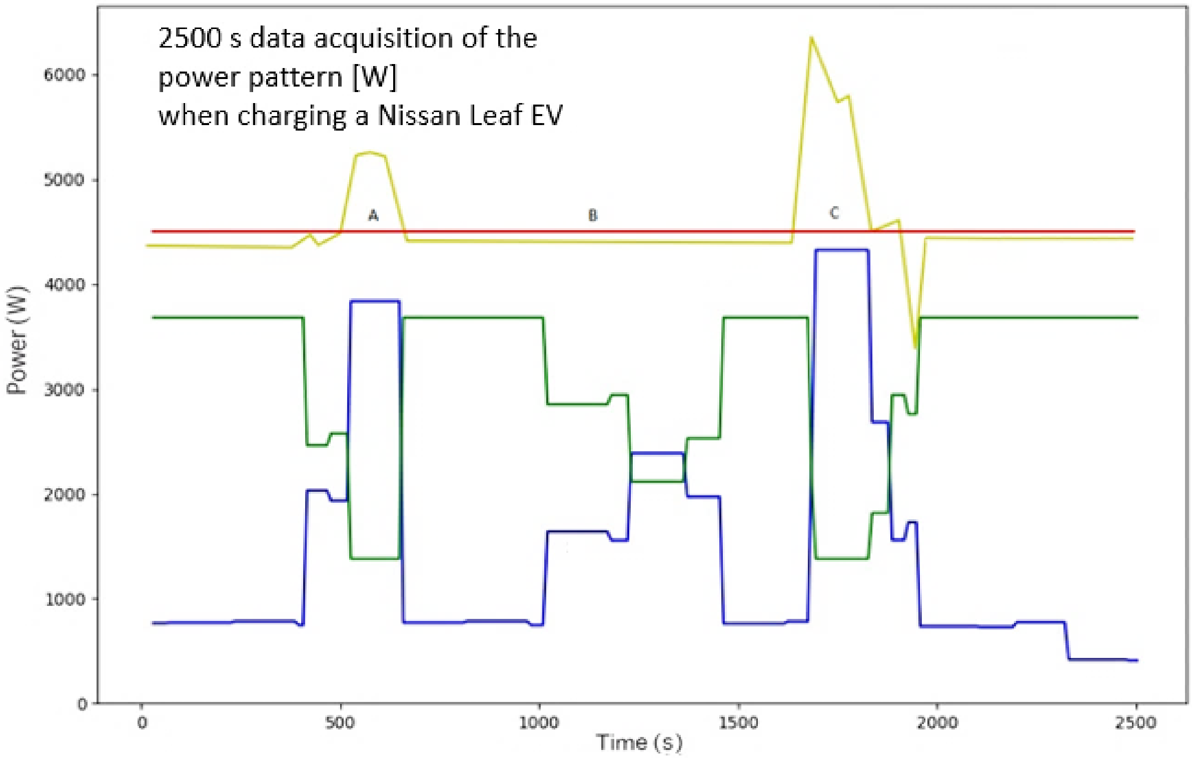

Figure 5. Time pattern of the applied power during the laboratory experiment with the Nissan Leaf EV (blue line: power of the loads; green line: maximum power of charge point; yellow/red line: instantaneous absorbed power and threshold value, respectively).

In the initial part of the graph—i.e. the part A—the system automatically modifies the delivery of the charging station by avoiding to exceed the simulated contractual power limit. With the introduction of a work load, an increase in the curve of the load occurs, which determines an excess vs. the contracted power limit (i.e. the yellow line). Again, the dynamic modulation system maintains a current value—which is supplied by the charging point—equal to the lower limit that was set in the parameters of the model: in this situation, the threshold value of the power is then overcame, but not electric blackout happens.

Some further reactions maybe implemented to refine this status:

- The implementation of a further modulation system such as, if the value of the delivered charging current is lower than the lower operating limit, a temporary blocking of the supply or the disconnection of the charging point is performed.
- A warning message (e.g. an SMS or e-mail or pop-up display alert) is provided to the user to inform about the high power and the risk of an electric blackout if the power of the loads is not reduced.
- The integration of a solution with the home system or AAL (Ambient Assisted Living) system, according to a hierarchical set of priorities of the loads [2].

In the last part of the diagram—i.e. part C—there is a new increase in the power of the loads in the laboratory to simulate what happened during phase (A). However, a peak of the total absorbed instantaneous power line is also observable. This peak derives from an inadequate reaction of the system in case of sudden loads occurring in the environment. Furthermore, this 'inertial' effect is due to missing data communication between the charging point and the charged EV.

4. Discussion & conclusion

A real-time system for optimal charging of the EVs has been presented. This system has been developed within the DriWe framework and it is intended to provide a reliable and stable solutions for domestic and industrial applications where electric loads can quickly change according to the real-time daily demand. The proposed system has been validated by using different electrical cars, namely a retrofitted Fiat 500, a Reanult Twizy and a Nissan Leaf. These vehicles were charged in the DriWe headquarter laboratory and power patterns vs. time were observed in order to test the response of the monitoring system. As can be seen from Figures 4 and 5, the dynamic load control system can easily be adapted to the various national requirements, conforming to all various situations comprising a single-phase power system. It has been tested in Italy taking into consideration two situations with different threshold values. According to the results obtained, the following considerations maybe mentioned:

1. A new standard and protocol over different car manufactures may be supported in order to make current charging point in the market able to interact and exchange data between the vehicle and the charging point: the data communication protocol may help to prevent the drawbacks reported in part C of Figure 5 (see also par. 3);
2. The proposed system should be integrated in a domotic environment in order to enhance the interaction of the recharging system with the daily life operating smart device in the AAL context [9];
3. Good communication via Wi-fi and a good network signal are necessary to avoid disconnections that could interrupt the connection between the smart device and the central system;
4. Continuous updating of the OCPP communication protocol is also desirable in order to improve the service for the end user.

Moreover, we should notice that further adjustments of the DriWe central system can be performed in view of the increasing number of the charge stations and circulating EVs. The central aggregator will therefore have to be strengthened as the main connection between the various elements of the system. Finally, with a view to the future development of the system, the following improvements can be considered:

(i) enhancing the communication network and the mathematical calculation model by recalling the device every second with a real-time collection of the responses.

(ii) implementing a novel feature of the DriWe system so that the mathematical model is activated only when an electrical load changes within the monitored environment.

Expansion of the offer vs. three-phase networks should be also clearly exhamined, establishing the requirements and specifications vs. the EVs market.

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Conflict of interest

The authors declare no conflict of interests in this paper.

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