

IMPLEMENTATION AND SIMULATION OF A DYNAMIC LOAD BALANCING SOLUTION FOR EV CHARGE POINTS UTILIZING SOLAR ENERGY

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ABSTRACT

This paper addresses the integration of solar energy with electric vehicle charge points through a load management and distribution system. It proposes an algorithm that dynamically allocates available power, considering building consumption, electric vehicle charger needs, and real-time photovoltaic system output. The system ensures efficient power distribution and stability. Simulation results demonstrate the algorithm's effectiveness in optimizing solar energy use, accommodating fluctuating power demands, and reducing costs, thus enhancing the sustainability and efficiency of EV charging infrastructure.

Keywords: Electric vehicle charging, EV charging, Load balance, Power management, Node-RED, Charge point simulation, PV cells

1. INTRODUCTION

In contemporary times, renewable and sustainable solutions such as electric vehicles [1] (EVs) or green energy sources like Photovoltaic (PV) panels are becoming increasingly important [2] [3] [4] [5]. A common challenge among these solutions is that the current infrastructure is inadequate to fully support the charging points for electric vehicles or effectively manage grid feedback from solar panels, leading to issues such as excessive voltage increases [3] [6]. Therefore, it is advisable to utilize the generated solar energy within the facility where it is produced. One promising approach is to divert surplus energy into the batteries of electric vehicles. Efficient operation of solar panels and electric vehicle charging points requires a load management and distribution system that appropriately allocates the available power and ensures the stable operation of the system [7] [8]. Besides, by using PV cells for charging vehicles, the price of the service can be much lower.

The first section of the paper outlines the problem and highlights the point of using solar energy for this purpose. It then briefly reviews existing solutions, explains the load balancing algorithm, presents simulation results, and concludes with the assessment of the solution and potential improvements.

2. SUBJECT

The paper presents the implementation and simulation results of a load balancing algorithm designed to distribute available power among electric vehicle (EV) chargers in an office building. In scenarios where the available power is insufficient to meet both the building's energy requirements and the charging needs, a management system becomes essential. This study specifically addresses the challenge of managing 23 AC (Alternating Current) EV chargers in an office environment where both the building's baseline consumption and the power generated by solar

cells fluctuate dynamically.

A critical aspect of this system is the prioritization of the building's power needs, meaning that the load balancing algorithm does not interfere with the building's or occupants' energy usage. In addition to power distribution, the algorithm is responsible for preventing the permanent system overloads, thereby ensuring stable operation.

Integrating renewable energy sources and EV charging infrastructure poses significant challenges, largely due to the limitations of the outdated power grid, which struggles to meet the rising demand. Storing surplus renewable energy is often not cost-effective, so maximizing on-site utilization is the most practical approach. This consideration motivated the development of a tailored solution to integrate renewable energy sources with the EV charging system, aiming to reduce costs and increase the available power beyond what is provided by the grid.

3. RELATED WORKS

Electric vehicle load management solutions can be categorized into two primary types: centralized and decentralized approaches. In a centralized framework, a central management system aggregates detailed information on usage patterns, user profiles, and system conditions to control key operational parameters, such as power output limits, pricing structures, and service prioritization. Conversely, in a decentralized model, individual charging points autonomously adjust their charging behaviors based on predefined protocols, enabling localized decision-making [9].

Some solutions for electric vehicle charging systems are based on game theory, treating the power requirements of EVs as unsplittable, meaning that the charger's output power is not limited. In this context, EV's need must be serviced by the charging station, and if it is not possible, drivers are incentivized to visit alternative stations for reduced service rates. These solutions are also capable

of integrating renewable energy sources. The primary advantage of this approach is its potential for fast charging, however, a possible drawback is the increase in pricing. Given these attributes, this approach is particularly suitable for public charging stations [9] [10].

Another promising method involves the distribution of the available power according to a specified scheme. This strategy allows all chargers to be utilized, although it may lead to a decrease in service quality as chargers output power can be lower than the EV's needs. This approach is well-suited for charging stations serving corporate fleets, where EVs are charged on-site. It offers high flexibility in terms of prioritizing charging sessions. There are for example, some fuzzy logic based priority systems that consider multiple parameters, such as energy pricing, state of charge (SoC), and charging duration and determines the priority level of a charging session [11] [12].

4. METHODS

To develop the load balancing algorithm, first the behavior of the different components has to be studied, like the PV characteristics, and the EV charging characteristics. Both have a typical power - time curve that was reproduced during the simulation. To implement and simulate the algorithm, we used Node-RED, which is an event-driven programming model [19]. Node-RED has several advantages, like its graphical user interface, which makes development easier additionally, it can be run on the server side or on the network edge, e.g. on a Raspberry PI.

4.1. PV generation

PV panels are more and more popular nowadays. In terms of EV charging, the PV power generation characteristic is not necessarily the best, these systems typically generate the most energy around midday, this can be clearly seen in Fig. 1 [13] [14] [15]. However, most EV user (more than 90%) start charging between 13:00 and 23:00 [16]. The blue curve (Day 1) shows the generated power on a slightly cloudy day: power generation can significantly drop in the absence of direct sunlight. The red curve (Day 2) is closer to an ideal PV generation curve. In the simulations, it was important to follow the real characteristics of the system, so a solar panel simulator was created based on these curves. Measured values were collected from a small-sized PV system.

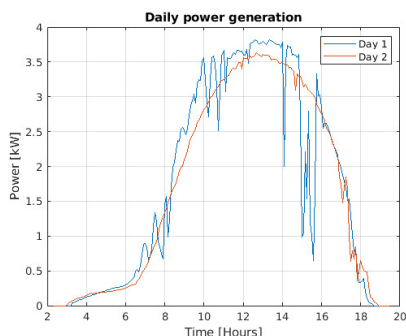


Fig. 1 Daily power generation curves of a PV system

4.2. Electric vehicle charging session

To create a realistic simulator for testing, the charging characteristics of the electric vehicles were also studied. The diagram on Fig. 2 shows a typical EV charging characteristic [16]. It is a 20 kW DC (Direct Current) charger's power consumption during a charging session. In the initial phase of charging, apart from minor fluctuations, the charging power can be considered constant, followed by a steep decline after reaching a certain charging level. The charging characteristic of, for example, a Li-Ion battery is slightly different [17], the constant section of the curve is truncated compared to a real battery characteristics due to the limited power output of the charger.

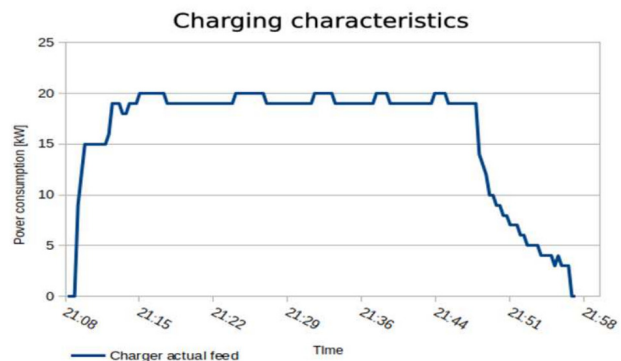


Fig. 2 Charging characteristics of an EV

4.3. The algorithm

The following load balancing strategy presents a straightforward approach aimed at tracking the electric vehicle's (EVs) charging pattern. It tries to allocate as much power as necessary to specific charging points (CPs) to ensure the fastest charging sessions, moreover, it imposes power limits when the overall consumption reaches the maximum available limit. The building's power requirements take precedence, it means if the available power is fully utilized, the chargers' power will be reduced to serve the building's needs.

On Fig. 3 the simplified block diagram of the algorithm can be observed. After the initialization, the following steps are executed in a loop for each charger to determine the new limit value.

To calculate the new limit, we need input parameters. As chargers usually provide consumption information during a charging session, it is easy to get the necessary data from the energy meter of the charger using either Modbus or the OCPP (Open Charge Point Protocol) [18] protocol. In our case, the second option has been used as OCPP enables the use of user and power management on the same protocol. Charge points typically send the actual charging power ($P_{chg_x_{act}}$) during a charging session as well as the actual limit value ($P_{chg_x_{limit_set}}$). Besides, some other parameter is required, like:

- The actual consumption of the building ($P_{building}$).
- The power generated by the solar system (P_{solar}).

- The maximum and minimum allowed power of each charge point ($P_{upper_limit_x}, P_{lower_limit}$).
- The power step-up ($P_{step-up}$) and step-down ($P_{step-down}$) values.
- The maximum available charger power ($P_{available_chg}$).
- The total power ($P_{available_total}$).
- Hysteresis value for the chargers (P_{hyst_chg}).
- Hysteresis for the entire system (P_{hyst_system}).

Hysteresis parameters make the system insensitive to small fluctuations in the input values and help to avoid oscillation in the calculated maximum charger limit. The total consumption of the building can be measured using a consumption meter placed on the input supply line. The generated solar power can be queried from the PV inverter.

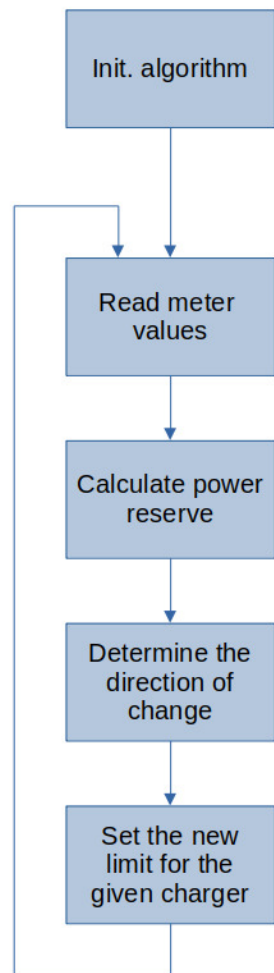


Fig. 3 Simplified block diagram of the algorithm

The second step is to calculate the available power reserve that can be allocated for the chargers. The total available charger power (P_{chg}) can be calculated by using Eq. (1).

$$P_{chg} = (P_{available_total} + P_{solar}) - P_{building} \quad (1)$$

Then we get the power reserve using Eq. (2).

$$P_{reserve} = P_{chg} - \sum P_{chg_limit_set} \quad (2)$$

In the next step, the algorithm needs to determine the direction of the change. Specifically, it must decide whether the charger power should be increased, decreased, or maintained based on certain parameters.

If the $P_{reserve}$ is greater than zero, Eq. (3) is true, and if increasing the charging power limit of a specific charger does not cause the sum of all charger's power limits to exceed the P_{chg} value, then the $P_{chg_limit_set}$ can be increased.

$$P_{chg_act} \geq P_{chg_limit_set} - P_{hyst_chg} \quad (3)$$

The charging power limit needs to be reduced if the following formula (Eq. 4) is true:

$$P_{chg_limit_set} \geq P_{chg_act} + P_{hyst_chg} + P_{step-down} \quad (4)$$

A lower threshold value must be defined, below which the limit value does not fall in normal operation. (During quick limitations, it is possible.) It was necessary to define as the chargers can start charging if their output limit is higher than a specific value. The Siemens chargers we used have a 6.4A lower limit value.

In certain situations, more drastic limitations are necessary. When the maximum available power is exceeded, for example, due to a sudden increase in the building's base consumption, a quick limitation is required to prevent fuses from blowing. In our case, the new limit can be calculated using the following equation (Eq. 5).

$$P_{chg_limit_set} = P_{chg_act} - |P_{available_total} + P_{solar} - P_{sum_actual}| \quad (5)$$

The algorithm's output is the maximum power limit for a specific charger ($P_{chg_limit_set}$). This value, which determines the maximum charging power for the EV, must be sent to the charge point. The charging power (P_{chg_act}) will not exceed the set limit, though it can be lower.

5. SIMULATION

As it has already been mentioned, the implementation and simulation of the algorithm were carried out in NodeRED. For the simulation, a charge point model was created that can reproduce the shape of the charging curve. The total energy fed into the battery has also been considered. To reproduce the characteristic on Fig. 2, I divided the charging curve into two parts. Until the 85% of the total energy, the curve was considered a constant value, and between 85% and 100% the new output power was the 80% of the actual output power. It is a relatively simple solution, but for this simulation, it was enough. Two charge points were simulated: Charger 1 has a maximum output power of 20 kW, and the total energy fed into the EV's battery is 10kWh, Charger 2 has a maximum charging power of 30 kW, the total energy is 30kWh.

In the simulation, we also considered the varying power demand of the building, and typical energy curve of a PV system. One simulation will be presented, in which two chargers were used, Charger 1 and Charger 2. The available maximum power that can be drawn from the grid is supplemented with the power generated by a PV system. In the simulation, we assumed that the generation curve of the solar system is similar to the curves shown on Fig. 1 (Day 1).

The main goal of the simulation is to show the dynamic behavior, how the available power is distributed, among the chargers, and how the algorithm handles the sudden changes in the building power demand as well as in the power generated by the PV system.

Table 1 contains the parameters of the simulation. It must be noted that during the simulation, we assumed that $P_{available_chg}$ is equal to $P_{available_total}$, meaning that all power could be used by chargers if $P_{building}$ is zero.

The simulation result can be seen in Fig. 4. The *Charger x limit* curves are the output of the algorithm. This is the maximum output power limit calculated for the CP. The *Charger x actual power* curves show the actual output power of the charger. The *Building power* is the consumption of the building, *Total power consumption* is the sum of the building and chargers actual powers, *Total power available* is the total available power that feeds both the building and the chargers. It consists of the grid power ($P_{available_total}$) and the power generated by the PV system (P_{solar}) thus its curved shape.

Table 1 Simulation parameters

Parameter	Value	Parameter	Value
$P_{available_total}$	30kW	P_{hyst_chg}	1kW
$P_{available_chg}$	30kW	P_{hyst_system}	1kW
P_{solar}	25kW	P_{lower_limit}	7kW
$P_{step-up}$	4kW	$P_{upper_limit_1}$	20kW
$P_{step-down}$	2kW	$P_{upper_limit_2}$	30kW

On the first chart, we can see the real output power of the chargers (continuous lines), however, it does not follow the shape of the one on Fig. 2. It is because the algorithm limited the output power of the chargers. It can be clearly seen that the output power never exceeds the limit value (dotted lines). Although the algorithm tries to allocate the available power equally, we can see differences between them. This happened because when quick limitation occurs, it is the next charger in the queue that will be reduced, regardless of the other chargers' status. When both chargers were under limitation (not reaching their nominal output power), the *Total power consumption* curve was very close to *Total power available* curve, which means that all the available power was distributed.

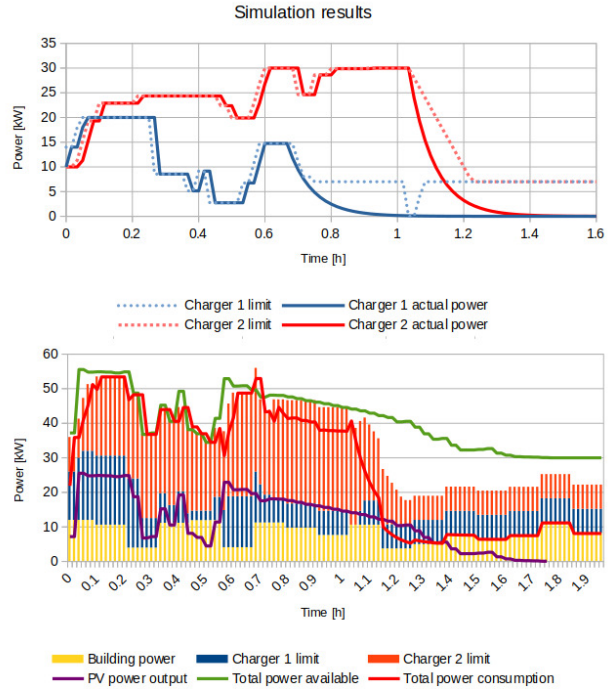


Fig. 4 Simulation results

The stacked bar chart shows the allocated power, that consists of the building power, and the limit values of the chargers. When this value is close to *Total power available* curve, all the power reserve is distributed. When the *Total power available* is exceeded, a quick limitation occurs. This means that the system is overburdened, and as we have no control over the building consumption, the charger power has to be reduced.

The simulation brought the expected outcome, furthermore, highlighted some weaknesses as well. Based on the results, it is ready to be tested in real word circumstances. In the future, by using data from real-word operation, the simulation environment also can be made more realistic, that is also essential for further development of the algorithm.

6. DISCUSSION

A critical point of the algorithm is the frequency of the execution, especially when it comes to integrating PV system into load management. The power generation curve of a PV system tends to change rapidly due to weather conditions see on Fig. 1 Day 1 curve, which can even cause permanent overloads in cases of low execution frequency. It must be noticed, that fuses have a current - time characteristics, that shows how much over current they can tolerate for how long. An example for this characteristics can be seen in Fig. 5.

Besides, the algorithm is also inclined to distribute power reserve unfairly, because the sequence of limit calculation of multiple chargers is based on the round robin principle. Usually, this happens, when the chargers have to be limited due to the lack of power reserve.

In future development phases, real-world testing data

will be crucial in providing detailed insights. This data will allow precise tuning of the algorithm parameters, potentially improving efficiency, additionally, insights derived from these results may reveal new directions for further development and expanding the system's capabilities.

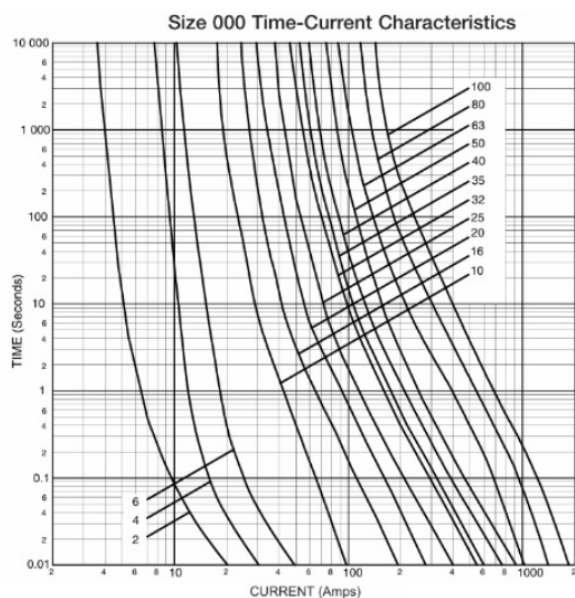


Fig. 5 Fuse characteristics [20]

Recent studies focused on priority system developments, based on the energy prices, SoC, and other parameters, or introduced different approaches like encouraging people to drive to other charge points if there is no enough power, in this case, the most important objective is to maintain the QoS (fast charging) [9] [10] [11] [12].

Our goal was to approach the problem from an other side, we designed a load management system capable of distributing available power by considering generated green energy and the power demand of uncontrollable appliances. The algorithm requires only energy meter readings and charging session data to calculate the limit values for the chargers.

7. CONCLUSIONS

The proposed load management and distribution algorithm effectively integrates solar energy with electric vehicle (EV) charging, optimizing the use of renewable energy within a facility. The dynamic algorithm successfully allocates power based on real-time consumption data, ensuring efficient and stable operation. Simulation results confirm that the system can handle fluctuating power demands, maximize the use of solar energy, and reduce overall costs. This approach enhances the sustainability and efficiency of EV charging infrastructure, demonstrating its potential for broader application in renewable energy integration.

Validation of the simulation result is in progress, however, the simulation result seems promising. We got

the expected outcome, and based on the simulation results, the algorithm appears to be ready for testing in a real-world application.

During the simulation and development process, some minor problem have raised, like the algorithm is inclined to distribute power unfairly, this could also been seen in the simulation. Another difficulty that ruins the efficiency of the system appears when the electric vehicle has a flatter run-off state on the charging curve. Since the parameters of the algorithm (like $P_{step-down}$) are fixed, the dynamic tuning of these parameters could improve the efficiency.

To enhance user experience, reduce charging fees and improve efficiency, we aim to develop a priority system that evaluates key parameters, including the state of charge (SoC), charging time, real-time energy prices, and power availability from photovoltaic (PV) systems. This system determines a priority level for each charging session. In scenarios involving vehicle-to-grid (V2G) interactions, electric vehicles can supply power back to the grid, that allows efficient management of the generated solar energy as well. With the priority system, we would like to study the different approaches, and their effect on both the user experience and the power grid. The final goal would be to find the most suitable solution, and method for different preferences.

For such system, the SoC (State of Charge) value is essential. Since standard AC chargers typically lack direct SoC data, it has to be estimated based on the previous, and current session information. Thus, the first step is to find a method, that gives a relatively accurate estimation.

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Received September 10, 2024, accepted November 20, 2024

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