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Synthesis of Electromobility Charging Profiles for the Planning of Commercial Charging Stations

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Summary

For planning and sizing of charging stations for electric vehicles load profiles are needed. In a project a new load profile generator for the synthesis of load profiles at commercial charging stations has been developed. This paper introduces the load profile generator, the methods used and some of the results.

Keywords: charging, electric vehicle (EV), infrastructure, load management

1 Introduction

The percentage of electric vehicles in circulation increases rapidly, which means that the charging of those vehicles becomes increasingly important. The charging of electric vehicles can, depending on the implementation, be either a great chance or a great burden for the future electricity grids. If the charging is implemented well, then electric vehicles can provide a major managed load that could help compensate intermittent renewable energy. If the charging is implemented poorly and everyone just charges whenever they like, with extremely high loads, then in many areas major grid reinforcements will be needed, once electric vehicles become more widespread.

Electric vehicles especially suited to increase the self-consumption of photovoltaic systems on commercial installations. But for planning the charging load profile is essential. Especially when utilizing a power tariff instead of an energy tariff, even short load peaks can significantly increase the energy costs.

Manually creating individual load profiles is not feasible for individual planners. To make it easier to build new commercial systems, the energy system planning tool “Sunny Design” of the SMA Solar Technology AG [1] has been extended to include a detailed electro mobility charging profile together with the Bern University of Applied Sciences. The application enables in the “Pro”-version a detailed and holistic planning and system simulation of energy systems with sector coupling, consisting of PV-systems, battery systems, thermal systems and charging stations. This paper will introduce the electro-mobility module and show some of the results.

2 Method

The model is split in two distinct cases. The first one model describes a known circle of customers with well-known vehicles. The second model describes stochastic arrivals of unknown vehicles. To illustrate the two cases: The first model describes for example a single-family house or a small office. The second model represents for example a charging station at a highway or a charging station at a supermarket.

The biggest challenge was simplifying the model sufficiently that it is easily usable by the system planners but still sufficiently detailed to provide a broad spectrum of realistic load profiles. The most important features for this were creating templates which can be selected by the user and then customized by the user and an easy and clear user interface (UI). This is shown in Figure 1.

It is important to note that the aim of the model is not to automatically size the charging station. Instead designing and sizing the charging station is left to the user and the simulation will then calculate the loads.

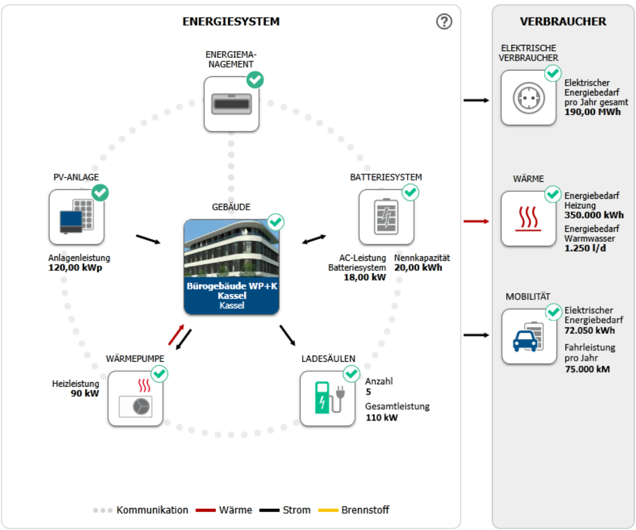

Figure 1: Main User Interface of Sunny Design for planning energy systems with electro-mobility.

2.1 Known Customers

In the case of the known customers the user defines one or more charging stations, one or more cars and a driving pattern.

This model shows for example a single-family house, a multifamily house or an office. In this model every car is modelled as an agent that is initialized at the beginning of the year and that then drives around.

The modelling is done using time windows that determine what the car is doing and when. There are driving and charging windows. For the driving windows a start time, end time and a travel distance is set. All of those can be randomly varied by user-determined amounts. This ensures a realistic profile, since it prevents unrealistic repetitiveness in consumption.

The agent always keeps track of the state of charge of the car. When the car reaches the charging station, it will try to fill up the battery as much as possible given the constraints of the car and the charging station on the maximum power. Of course, the number of cars and charging stations does not have to match. It is possible (and in many cases actually reasonable) to oversubscribe the charging stations. Figure 2 shows a screenshot of the user interface for defining a single car. It was discussed to enable modelling people with alternating weekly schedules such as shift workers, but it was deemed to increase the complexity significantly with little benefit. With this modelling approach it is easy to create different behaviour patterns for every day of the week. Note that it is possible to set vacation times for the customers. Especially for institutions like schools, recreational seasonal resorts (skiing, theme parks etc.) or universities this is relevant, since without modelling the vacation times, the self-consumption of a PV-System, for example might be significantly overestimated when during the summer almost everyone is gone.

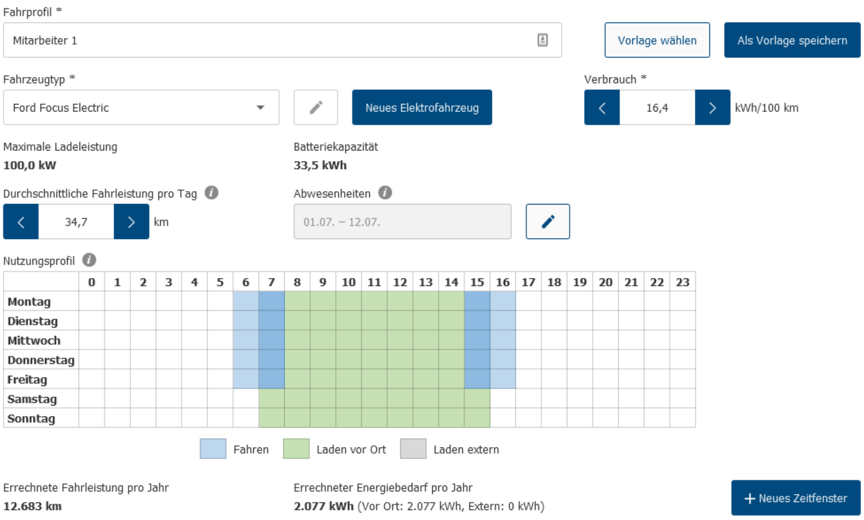

Figure 2: Window for defining a behavior pattern with example settings for an office workers that charges at the office

The definition of the charging stations is shown in Figure 3. It uses the same grid pattern for letting the user select on which days and at which times the charging station is available. It is possible to install as many charging stations as needed and it is also possible, to limit the combined power demand to a fixed value. For example, even if 10 charging stations with a theoretical combined power of 220 kW are installed, with this setting it is possible to limit the total power to only 50 kW. This is relevant when the station owner is paying for power (instead of energy) and wants to ensure that costs stay low. For example, an office might want to provide 10 charging points for 10 workers. If every worker has a one-way-commute of 20km, then the total energy demand per car per day would be 40km*20 kWh/100km = 8 kWh/day. If there is no controlled charging and every charging point provides 22 kW power, that would mean the office is paying for 220 kW peak power and all cars are fully charged within half an hour of arrival at the latest. Obviously, there is no need for that. If the maximum total charging power is limited to 15 kW, then still all cars are charged after less than 6 hours and the costs are significantly lower.

For the charging windows it is possible to set the charging location to either at the simulated location or at an external location. This enables the user to model the situation where part of the charging is performed at home and another part is performed at the office, for example.

For the charging stations it is possible to set a strategy on what to do, when the car is fully charged. If for example an office has 20 people with electric cars but only 5 charging points, sometimes there are rules that oblige people to go out and disconnect their car as soon as it is sufficiently charged to better utilize a spare resource. Most likely the loss in productivity is much larger than the cost for installing some more charging stations, but such arrangements have been observed in reality before. On other cases, people might just leave their cars plugged in, until the end of the workday. In Sunny Design both strategies can be modelled.

For the driving pattern it is possible to randomly vary both distances and exact arrival times with a normal distribution to avoid creating unrealistically high peaks. For example, the user defines when he or she is driving to work, how far the commute is and when they return. With these parameters an agent-based simulation model is then initialized and for every time step of the year, the location of the car, the state of charge of the battery, and if the car is connected to a charging station. This agent-based approach builds upon the lessons learned when creating the residential load profile generator in [2].

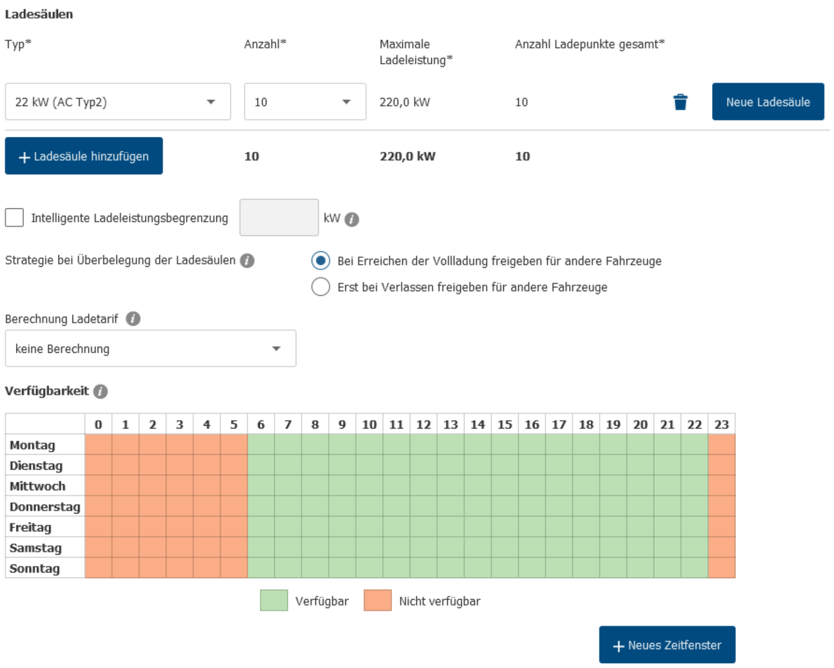

Figure 3: Window for defining charging station availability

Another noteworthy feature is that, if due to bad model parameters the battery runs empty, then an "emergency charging" will be activated, which shows exactly how much energy would be needed from external charging stations to cover the distances. For example, if the user tries to model a daily drive of 200 km with a car that only has a range of 100 km, then the other 100 km per day, would be covered by emergency charging and communicated to the user.

2.2 Stochastic Arrivals

If the users are not known, then a stochastic arrival model must be used. Here the model enables the planner to define for every day of the week, arrival windows with a certain number of arrivals. Additionally, the planner can define the duration of the stay, the state of charge of the battery in the cars upon arrival and the possible charging power for each car. The user interface for this is shown in Figure 4. Such an arrival window in text form might look like "between 17:00 and 19:00 between 15 and 20 cars will arrive. They will stay between 30 and 90 minutes at the charging station and will need between 20 kWh and 40 kWh of energy. The maximum charging power for the cars will vary between 3 and 22 kW". Per day multiple such arrival windows can be defined. Thus, it is possible to model the varying arrival rate of cars over the day for a supermarket or a hotel.

Especially for the stochastic case, the behaviour strategies are very relevant. Here there are two different ones: the first one, determines what to do, if no charging point is available on arrival and the second one, determines how to proceed if the allocated time runs out before the car is fully charged.

For example, at a supermarket people might arrive, plug their car into a charging point if one happens to be available and go shopping. When they are done shopping, they will most likely leave and not sit in the parking lot for the next hour waiting for their car to finish charging.

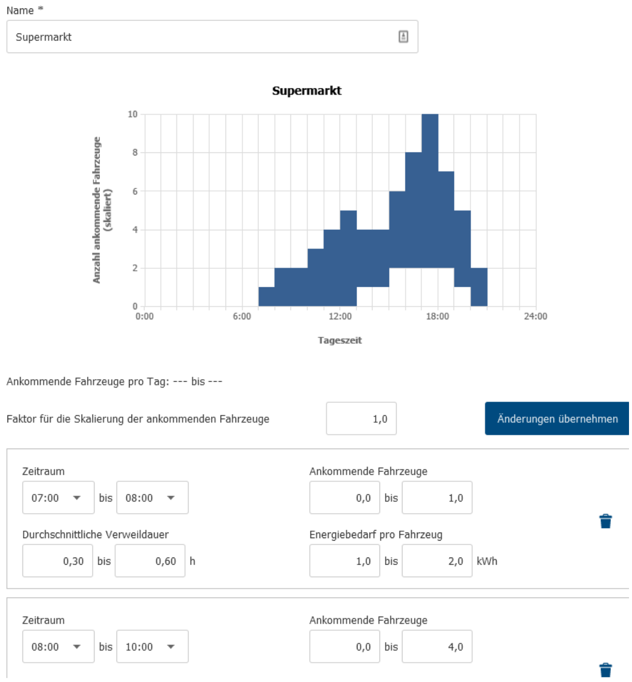

Figure 4: Window for defining arrival patterns for the stochastic arrival module

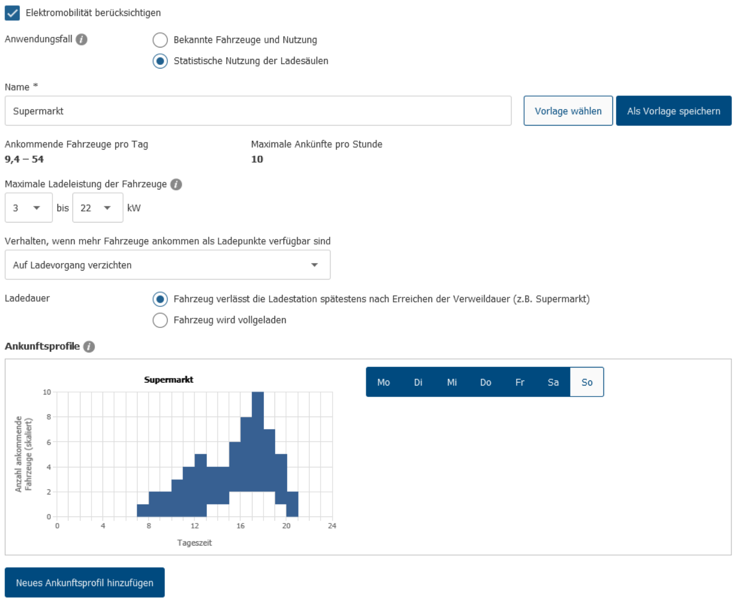

Figure 5: Window for setting the behavior strategies and other parameters for the stochastic arrival mode

At a highway charging station where people arrive with almost empty cars, they will wait until a charging point becomes available and then only leave after their energy demand is filled.

In the second case it is frequently easy for long queues to develop if the number of charging points is too low or the available power is insufficient. In these cases, the model will provide an “error message” and enable the planner to solve the problem by increasing the number of charging points or decreasing the number of arriving cars.

2.3 Predefined cases

Based on statistical data and user data, the following predefined cases were defined:

Known cases:

- Typical office worker charging at home
- Soccer-Mom that drives her children to school, goes shipping and travels around the city
- Multi-family house with 10 office workers that charge at home
- Office that has 10 charging points with 10 workers who charge at the office every day

Stochastic Arrivals:

- Hotel
- Supermarket
- “Gas” Station – public equivalent to a Tesla super charger.

Of course, everything is fully configurable by the user. But so far, this seems to cover the majority of the use cases that the planners commonly encounter.

2.4 Limits of the model

[3] shows measured charging profiles from different cars. It is visible that those tend to have an exponential decline towards the end of the charging process. The Sunny Design model on the other hand models the cars as having a perfect rectangle curve. Thus, it will slightly overestimate the utilization and underestimate the power demand towards the end of the charging process. It is planned for the next release to implement measured charging profiles for the various cars.

3 Results

3.1 Validation

Validation of a model happens always in two stages: the first stage is verifying that for a given input, the model yields the expected output. This test was performed very thoroughly for the developed solution. The source code is almost fully covered by unit tests that verify that everything is working correctly. Additionally, systematic parameter variation tests were performed, and the results compared with the expected output, for example the total energy consumption, the peak load times and much more.

The second stage of the validation is ensuring that input parameters from a real system yield a result that is very close to the measurement result. The second part proved to be more challenging due to a lack of detailed measurement data from large real world systems. Instead the results were compared to results from other scientific studies such as [4] or [5]. This also showed that the results of the model are plausible, but the model oversimplifies the variance in behaviour. Typically, human behaviour varies quite a bit over the seasons and from day to day, which this model doesn’t reflect right now. The more sophisticated, but much more time intensive LoadProfileGenerator from the same authors [6] yields more realistic profiles, but has a much steeper learning curve.

3.2 Results for a Single-Family House

The results for a single-family house with an office worker that drives 12’500 km per year are shown in Figure 6. The person drives to work every day, goes shipping once per week in the evening and visits family every Saturday. This behavior pattern is of course very simplified, but already yields interesting results regarding the required charging power. In Figure 6 the maximum charging power was varied between 2 kW and 22 kW and even with 2 kW the demand can be completely covered on every day of the year. The driver is never in any danger of encountering an empty battery. This shows that even installing 11 kW chargers is oversized for almost everyone.

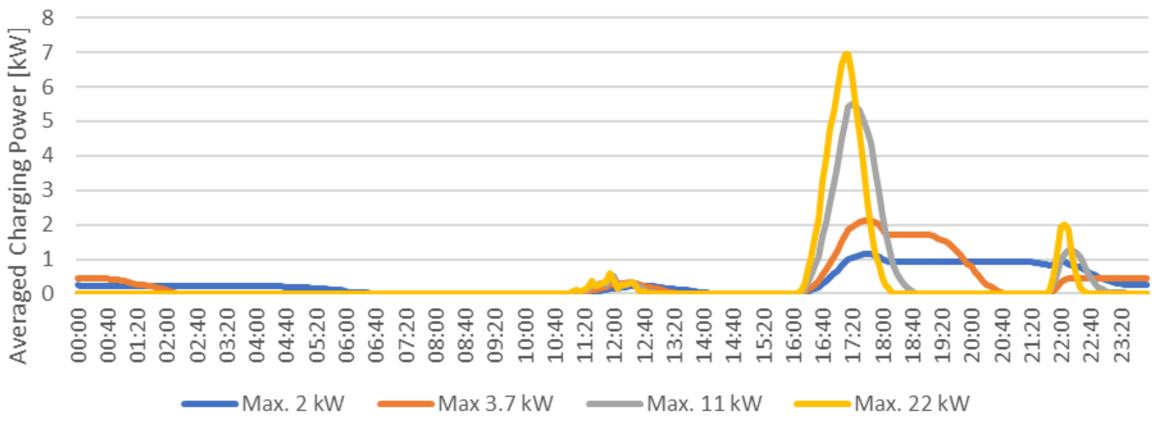

Figure 6: Yearly average of the charging power for a single-family house for different charging station types

3.3 Results "Hotel"

One of the more surprising results of the modelling were the high power demands for hotels that want to reliable charge their customers cars overnight. It seems to be a reasonable assumption that most hotel guests travel significantly further than 100 km to the hotel. If the average hotel guest needs 50 kWh/night that means for average days a demand for 5 cars of 250 kWh over 8 h, or, with perfect load balancing, just under 32 kW sustained power demand over the entire time. But if 5 Teslas with empty 100 kWh batteries arrive, it would mean about 64 kW of sustained power demand, if they all want to leave on time in the morning.

Figure 7 shows the combined power demand for five charging stations, averaged over one year for on average 5 arrivals per day, spread out over the evening. It is visible that while in most cases charging is mostly finished around 4 AM, sometimes the charging is not finished until 7 AM.

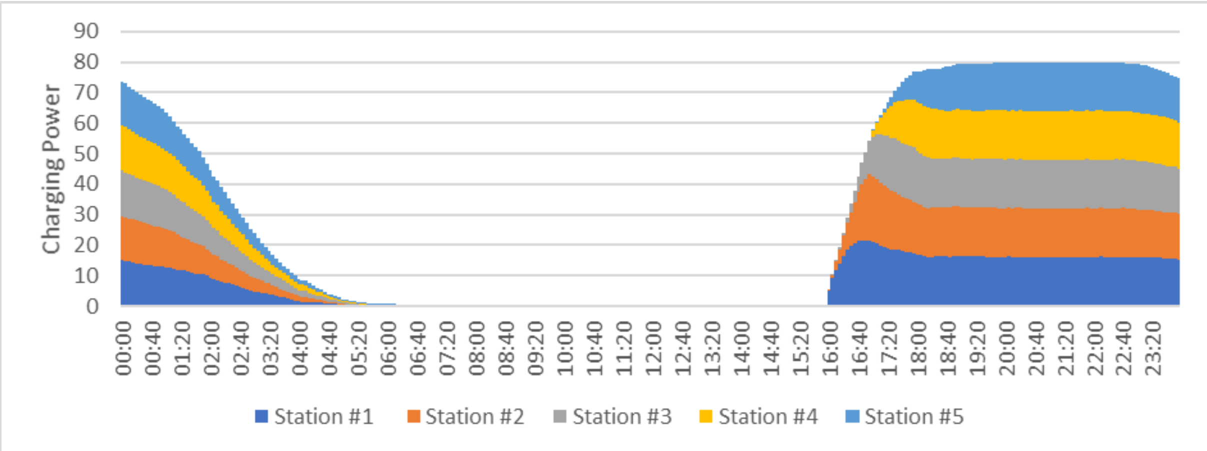

Figure 7: Yearly averaged charging power demand for a hotel with 5 charging stations limited to a maximum power draw of 80 kW

3.4 Results "Supermarket"

Figure 8 shows an example for the charging behaviour of a supermarket with 10 charging stations.

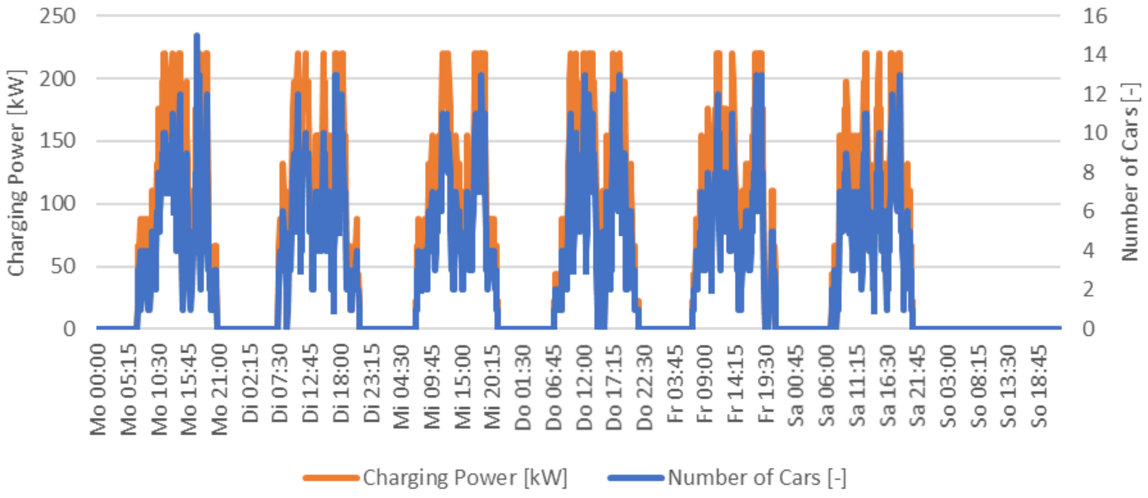

Figure 8: Synthetic charging profile for the charging stations at a supermarket

If a supermarket decides to offer 10 charging stations for customers with 22 kW maximum charging power each, then an additional power of 220 kW at the substation for the supermarket will be required. At a typical German power price of 20 € / kW / month, this will lead to yearly costs of 52.800 €. But it is easily visible in the charging profile that the maximum power will only be required for brief period each day. When calculating the entire year, then only 0.8% of the time a charging power over 180 kW would be required.

Therefore, such public charging station installations have a large cost saving potential by combining a photovoltaic system, a buffer battery storage and some intelligent charging control. If for example the maximum grid demand can be limited to 100 kW and the load peaks can be covered by a battery, then that would provide savings of up to 24.000 €/year. At these price ranges installing battery systems can already be economic with today's prices. This example shows why it is so important to have detailed load profiles, since only with the load profiles is it possible to correctly size the system and making sure that it will be able to cover the demands. It would be worth thinking about though, if it would be cheaper to install a cold storage for the air conditioning and the freezers instead, since that might be significantly cheaper.

4 Conclusion

In conclusion this paper will hopefully help other people with the challenges of creating a good model for electro-mobility charging. The most important take-away is that creating good charging profiles is essential for correctly sizing charging stations and avoiding later frustrations with undersized or oversized stations, large utility feeds or frustrated customers.

Another relevant conclusion from the project is that for single family housing, charging with a single phase 3.7 kW connection is really sufficient for pretty much all use cases. Having larger charging stations will even at low penetration rates rapidly overload the local low voltage grid, since EV-charging can have a very high concurrency, when everyone comes home from work at the same time and plugs in their car.

With this addition to Sunny Design it has become significantly easier to integrate charging stations into renewable energy systems. The integration of photovoltaic systems and charging stations will be a significant step towards the decarbonising of traffic and could provide a major boost to the installation of new photovoltaic systems.

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Presenter Biography

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Urs Muntwyler is Professor for Photovoltaic and leader of the PV Lab of the Berner Fachhochschule in Burgdorf since 2010. He organized the „Tour de Sol 1985-1992“, the first solar car race in the world. Muntwyler is involved in the PV since more than 40 years and had several companies in the PV - field. He published more than 200 articles and books on solar energy, photovoltaics, electric vehicles and solar cars. Muntwyler was chair of the "Technical Collaboration Program Hybrid- and Electric Vehicles" of the International Energy Agency IEA 1998-2018.