EVALUATION OF DIFFERENT CONTROL ALGORITHM WITH LOW LEVEL COMMUNICATION REQUIREMENTS TO INCREASE THE MAXIMUM ELECTRIC VEHICLE PENETRATION

Felix LEHFUSS
AIT Austrian Institute of Technology GmbH – Austria
felix.lehfuss@ait.ac.at

Martin NÖHRER
AIT Austrian Institute of Technology GmbH – Austria
martin.noehrer@ait.ac.at

ABSTRACT

This contribution discusses three different types of charge control approaches: A local voltage driven control, a central power driven control and a combination of these two. These three approaches have been simulated and evaluated in a low voltage grid with around 300 customers and three different penetration levels for EVs (22 %, 55 % and 85 %). The main results of this contribution are the direct comparison of different control algorithm in their capabilities to rise the maximum grade of EV penetration for low voltage grids without a cost intense grid expansion. The implemented algorithms have deliberately been designed as simple as possible with only one control parameter in order to allow an evaluation of the effects of each control without generation cross correlation issues caused by different input parameters.

INTRODUCTION

The mobility system of the future will have very strong synergies with the energy system. It is expected that electric mobility will be one major part of tomorrow's mobility system. Keeping the 2 °C climate goal in mind it is expected that by 2030 in Europe 60 % of all sold vehicles have a battery that can be charged via the electricity grid [1]. This penetration includes all vehicles that have the ability to be charged with energy from the electricity grid, namely full battery vehicles (BEV) and plug in hybrid vehicles (PHEV). The expected rise in the penetration of electric mobility generates near future challenges for today's distribution grids. High power electric vehicle supply equipment (EVSE) are expected to be mainly connected directly to the medium voltage grid whereas low power private or semi-private charging stations will be connected directly to the low voltage grid. Past projects have shown that the rise in electric vehicles (EV) penetration will cause much more of a power issue than an energy issue (e.g., the Danish Nikola project [2], the Austrian V2G-Strategies project [3]). These power issues will affect the low voltage grids. In order to mitigate the cost expensive "coper based" expansion of low voltage grids approaches like smart charging and Vehicle to Grid (V2G) are often discussed who base on the concept of externally controlling the charging process of the EV. Both, smart charging as well as V2G, are very communication intense and prone to interoperability issues. These issues are tackled by high level communication standards like IEC 15118 and IEC 61850.

This paper evaluates a real low voltage grid in different

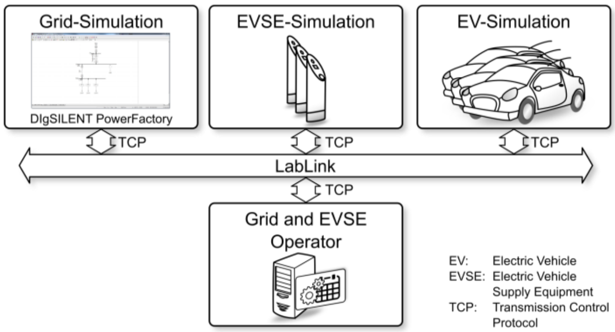

Fig. 1. Used co-simulation framework for EV grid integration.

high EV penetration scenarios for three different control approaches. One approach is a local or decentralised charge control that is implemented directly in the charging infrastructure and does not require external communication. The second one is a centralised approach which utilizes a central grid surveillance that communicates control signals to the different charging stations connected to the grid. And the third approach presents a combination of the previous two.

This contribution focuses on (semi-) private charging stations that are located at local households who do not support fast charging. It is assumed that controlling fast charging does not make a lot of sense as the whole purpose of fast charging is to charge the car as fast as possible which would be interfered by a power limiting charge control. Furthermore it is assumed that fast charging stations with a high power rating are connected directly to higher grid levels as this enables the required high power transfer.

The aim of the paper is not to define either a perfect decentralised or centralised control approach but to evaluate the differences between two fundamental diverse design approaches for the controlled charging of electric vehicles.

SIMULATION ENVIRONMENT

For the execution of the simulations a Co-Simulation framework for the grid integration of EV that is described in [4] is used. The environment–shown in Fig. 1–consists of different independent simulators for each domain. The Grid-Simulation calculates the power flow in an electric distribution grid. The EVSE and the EV-simulators calculate the behaviour during the charging processes of virtual vehicles. The last simulator in this structure is the Grid

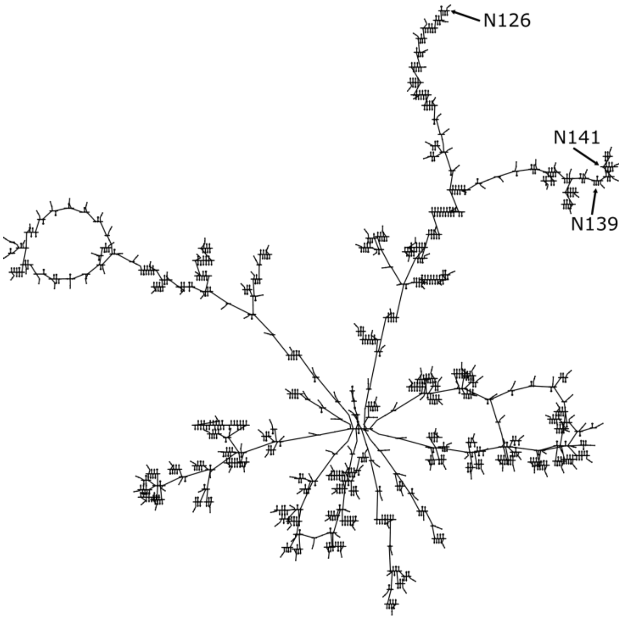

Fig. 2. Topology of the low voltage distribution grid used for the simulation.

and EVSE-Operator that executes the charging algorithm for the smart charging simulations. All these components are connected using TCP connections to the LabLink. The LabLink is an especially developed message router that distributes information between all components within the framework. It is also used to synchronize all simulators in time.

Electric Grid

For the simulation scenario a large low voltage distribution grid that exists in reality is chosen. Fig. 2 shows the low voltage grid discussed in this contribution.
The completely anonymized grid consists out of 280 households and has a total energy demand (without EV) of 1200 MWh per year. The transformer has a maximum load of 680 kVA and the longest feeder has a length of 750 m. For the specific EV simulation in this contribution the photovoltaics sources are disabled. This grid model represents a real grid in Austria.

Electric Vehicles Behaviour

For the simulations executed three different penetration scenarios have been chosen. With values taken from Statistics Austria [5-6] there are currently 1.2 vehicles per household in Austria. In this contribution different penetrations, one of 22 % that represents a total of 82 EVs, one of 55 % representing a total of 201 EVs and finally 85 % which would translate to 306 EVs are chosen for the analysis.
The electric characteristics of the virtual vehicle model are a common configuration for a currently available EV. The charging is based on a single phase connection with a maximum charging power of 3.5 kW. During the simulation the vehicles try to charge at every stop at a charging station.

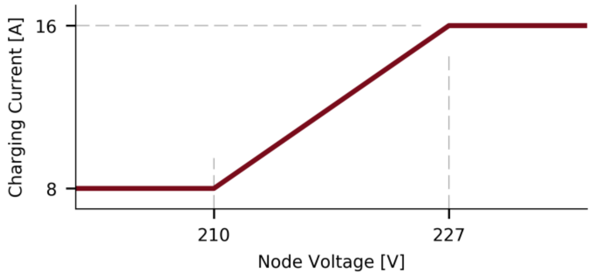

Fig. 3. Local and decentralised control algorithm built-in within the EVSE.

IMPLEMENTED ALGORITHMS

For this contribution it was chosen not to implement one of the various existing smart charging algorithms [7] but to validate the effects of two different fundamental methodologies that can be used for controlled charging of electric vehicles.
The charging algorithms introduced follow a “semi smart” approach. It does not fully fit into the definition of smart charging as the charging process does not allow the vehicle user to define control parameters (as e.g. a departure time or a State-of-Charge at departure). Never the less it is considered to be “semi smart” as it is controlled by a third party that is neither the car nor the charging infrastructure.
It was chosen as a design parameter for the control algorithms implemented to have only one controller input in order to minimize the possible effects or cross-correlations of different input parameters. The aim of the evaluation at hand is not to re-invent smart charging control algorithms but to clearly evaluate two different fundamental design approaches.
The implemented charge control algorithms have deliberately not the capability to switch off the charging process entirely but only to reduce the charging current to the minimum current of 8 A.
As stated in the introduction it is not the intention of this contribution to define and develop a novel charging algorithm but to evaluate the effects different control structures would have on a low voltage grid. The described control algorithms are intentionally very simple and would most likely not withstand a real world implementation. Never the less their rudimentary design allows for an evaluation of their different effects and can provide a basis for future algorithm design.

Local control

The local control algorithm measures the grid voltage at the charging station itself and sets the maximum charging current that may be utilized by the car in respect to the measured voltage. Fig. 3 shows the implemented I(U) control algorithm. In order to avoid massive oscillations of the charging current that would be expected to have a negative effect on the grid a delay of 60 seconds is introduced in the control after each change of the charging

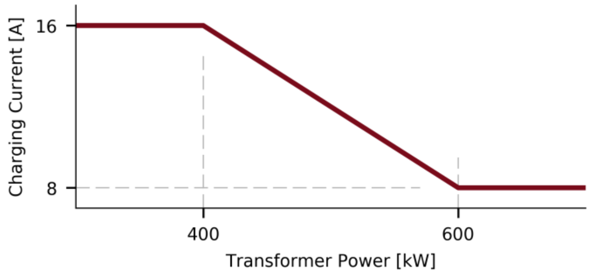

Fig. 4. Centralised control algorithm built-in within the

current before the next alternation is allowed to be executed.

This local control approach can be implemented with low level communication only. The required communication standard between the charging station and the car would be the IEC 61851 [8] which is already implemented in every EV and charging station. A high level communication, e.g., based on the IEC 15518, is not required for this approach.

The control can be implemented directly inside of the charging station itself which was one of the main criteria chosen for the local control approach. No communication with either the grid or any other external third party would be required in order to implement such an algorithm.

Centralised control

The global control algorithm measures the power at the transformer that connects the low voltage grid to higher grid levels. In the same way as the above introduced local control, the central control derives the maximum charging current that the charging stations are allowed to provide to the cars linearly in dependency to the transformer power. Fig. 4 depicts this implemented algorithm. The controller's output will be used by all connected vehicles simultaneously to change their maximum charging currents. In order to avoid oscillations a delay of 60s for changing control signals has been implemented.

The central control algorithm is not as simple as the local one as it would require a communication between the central measuring device at the transformer itself and the charging stations connected to the low voltage grid. For this publication this communication was assumed to be given an operational. A real life implementation of such a communication can have various designs and the exact specification of this communication is not of importance for the principal evaluation of the results of such a charging algorithm to low voltage grids.

Combined control

In addition to the local and the central control algorithms implemented a combination of both was also considered. This combination uses the two algorithms described above who run in parallel. The lowest calculated charging current will be used by the charging infrastructure to control the vehicles' charging current.

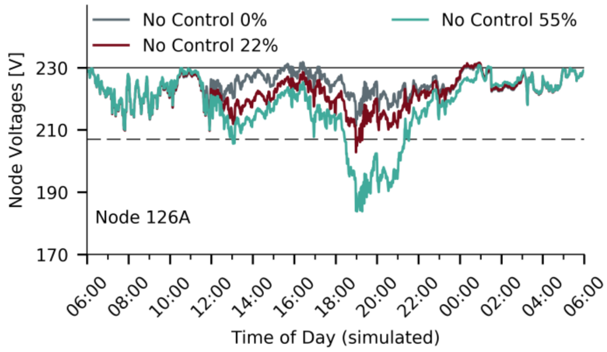

Fig. 5. Voltage at critical grid node at different penetration scenarios and uncoordinated charging

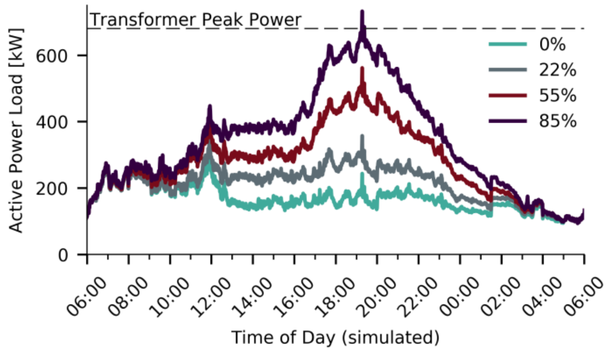

Fig. 6. Transformer Power at different penetration scenarios and uncoordinated charging

EXECUTED SIMULATION SCENARIOS

For the evaluation of the effects of different charging algorithms to the selected low voltage grid multiple simulation scenarios have been executed. First a simulation of the given low voltage grid was conducted with no EV penetration, in order to have a reference scenario that shows the behaviour of the grid without any additional load caused by electric vehicles.

The four different control algorithms (including uncoordinated charging as a control algorithm) being:

- Uncoordinated charging (No Control)
- Charging with the local control
- Charging with the central control
- Charging with the combined control

Each of them has been simulated for three different penetration rates of 22 %, 55 % and 85 % as described previously.

RESULTS

For the low voltage grid that was chosen to evaluate the effects of different charge control algorithms a penetration of 22 % electric vehicles who charge at a maximum power of 3.5kW does not cause grid issues. It is also

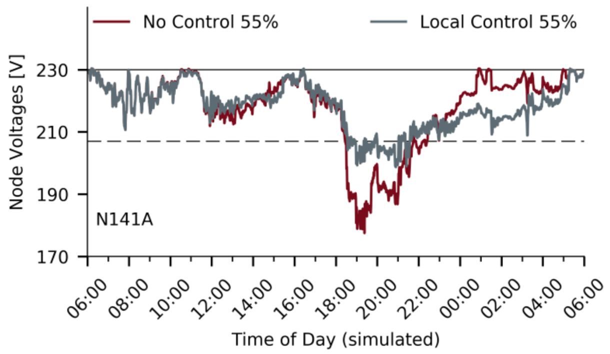

Fig. 7. Voltage at critical grid node at 55% EV penetration

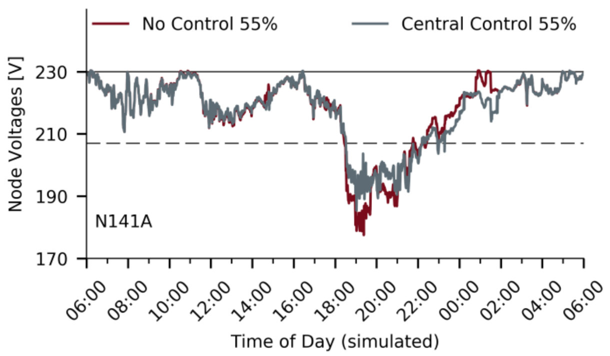

Fig. 8. Voltage at critical grid node at 55% EV penetration

worth noticing that this comparatively low charging power did not cause any EV to have any issues with its SoC. Fig. 5 and Fig. 6 shows that both, the voltage (represented at a critical node) stays within the required voltage band of 1.1 p.u and 0.9 p.u and the total power at the transformer does not exceed the maximum transformer load. However increasing the penetration further to 55 % and 85 % respectively causes massive voltage issues. The most critical nodes have been at the very end of long feeders, which is an expected result when examining voltage issues for heavily loaded low voltage grids. This unfortunately would result in an unfair disadvantage for the EV users who happen to have their charging station connected further away from the transformer.

The local charge control algorithm implemented for this contribution is too weak to fully compensate the voltage issues that are caused by a penetration of 55 % EVs but reduces the magnitude and time of the voltage band violations significantly. This can clearly be seen in Fig. 7.

The central charge control algorithm also has beneficial effects in reducing the voltage band violations, shown in Fig. 8. Never the less the impact is lower that it has been with a local control. In addition the global control implemented uncovers one of the biggest weaknesses of a centralized control for EV charging. Due to the fact that all charging infrastructure in the grid is controlled at the same concurrence effects lead to oscillations in the grid voltage and the transformer power. (Fig. 9)

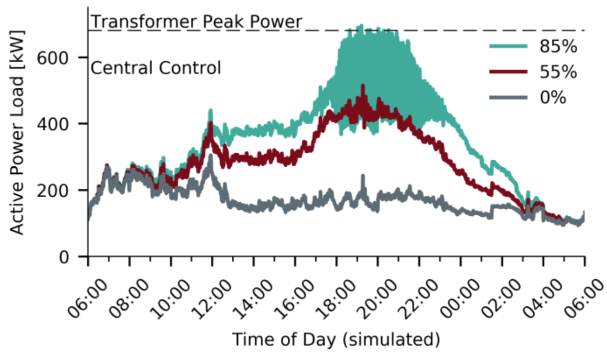

Fig. 9. Central control algorithm built-in within the transformer station.

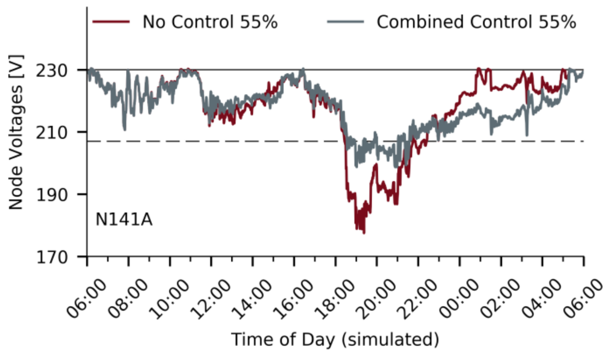

Fig. 10. Voltage at critical grid node at 55% EV penetration

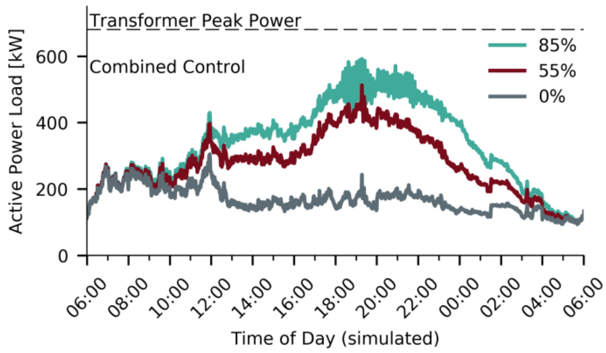

Fig. 11. Central control algorithm built-in within the transformer station.

The combined control algorithm does not provide a further improvement compared to the local control on its own regarding the grid voltage at the most critical grid nodes (representatively depicted for one node in Fig. 10). An added value of the combined approach can be found in the transformer power. The maximum transformer power was reduced (compare Fig. 11 with Fig. 6). However this reduction comes at the trade-off of additional oscillations and thus risks of instability. If the reduction in the maximum transformer power is worth this trade off can be stated as highly discussable.

DISCUSSION

This contribution evaluates the impact of different charge control methodologies for low voltage grids with a high penetration of electric vehicles. In order to assess methodological results very simple charge control algorithms have been implemented. This enables to identify the key strengths and weaknesses of different charge control approaches.

The two charge control approaches that have been compared are a local charge control that can be implemented directly inside of the charging infrastructure with no further external communication required and a centralized global charge control algorithm that measures the transformer power and then communicates the maximum charge current to the charging infrastructure connected to the low voltage grid.

The implemented local control algorithm who utilized the grid voltage at the charging infrastructure as control input provided surprisingly good results and thereby delivers a possible basis for a further development of a more sophisticated charge controller. The very simple design of the controller was expected to cause voltage oscillations which did not happen in the executed simulation scenarios. It was shown that such a local charge controller will not be capable to solve the grid issues that are caused by very high penetration rates of electric vehicles on its own but is should be considered a valid starting point. A possible first improvement regarding the grid stability could be introduced by giving the control algorithm the ability to stop the charging process which was not implemented deliberately for this contribution.

The centralized global charge control that was implemented utilized the transformer power as control input. In the executed simulation scenarios this approach did not deliver results that were convincing. The beneficial effects of such a control are smaller than those of the local control algorithm. In addition to this smaller impact the central control algorithm introduced oscillations that were mainly caused by concurrence effects due to the fact that the entire charging infrastructure in the grid was controlled and triggered at the same time. This effect would have to be reduced drastically in order to allow a real world implementation.

CONCLUSION

This contribution discusses two different methodological approaches to control the charging of electric vehicles in a low voltage grid with high EV penetration. The different approaches discussed are a decentralized local control and a centralized global control.

The evaluations conducted in this paper suggest that a decentralized local control of vehicle charging has a higher potential to support grid stability. This decentralized approach followed a simple voltage driven controller design that reduces the maximum charging current.

The centralized global control algorithm controls the charging current of all charging infrastructure connected to the low voltage grid at once and thus causes high power and voltage oscillations. This shows a fundamental weakness of centralized approaches for charge control: concurrency effects.

The amplitude of the positive impact a simple voltage driven local charge control has on sustaining the grid was surprisingly high which leads the authors to the conclusion that further investigation of such decentralized charge control algorithm is required.

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