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Design and Validation of a Smart Charging Algorithm for Power Quality Control in Electrical Distribution Systems

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ABSTRACT

Electric mobility leads to an increasing challenge for power grid operators, particularly due to its irregular and unknown load profiles. In order to keep up with increasing power demand of charging processes, besides better predictions also the active control of charging processes will be necessary to minimize infrastructure costs. This work deals with a distributed smart charging approach which considers real-time grid conditions for supporting the power quality in electric distribution grids in terms of congestion and voltage management. Our approach adopts the traffic light model to indicate the current state of the low voltage grid, which allows smooth changing of the charging power to avoid drastic changes of the grid state. The algorithm is validated by a series of experiments on two setups: Pure software (co-)simulation and Power *Hardware In the Loop* (PHIL), where physical charging stations and electric cars are controlled in a laboratory setup.

CCS CONCEPTS

• **Hardware** → **Smart grid**; **Smart grid**; • **Computer systems organization** → *Real-time system architecture*; *Real-time system architecture*;

KEYWORDS

Smart Charging, Power Quality, Electric Vehicle Charging, Charging Station, Voltage Control, Traffic Light Model

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1 INTRODUCTION AND RELATED WORK

Undoubtedly, guaranteed immediate and fast charging can only be realized with sufficient grid capacity at the connection point, which is required e.g. for public *Charging Stations* (CSs). However, intelligent ICT-based solutions are needed for economic and ecological reasons. In this regard, smart utilization of available capacity can help to reduce grid connection costs. Therefore, this paper proposes a solution for an active grid controller at the low voltage level.

All smart charging approaches mentioned in related work can be grouped in two main categories: Approaches of charging management and scheduling, e.g. [3, 4, 8, 9, 11, 12], and approaches of real-time charging control, e.g. [1, 2, 6, 7, 10, 13]. Our proposed solution belongs to the later and differs from the existing approaches in the following points: It is completely distributed; The proposed event-driven architecture for collecting data from the grid allows to react in real-time to two different kinds of events (asset overloading and voltage magnitude threshold violations at certain points in the grid). Furthermore, we applied a rapid prototyping approach for networked smart systems [5] in order to test the proposed architecture and ensure a safe deployment in a field test region in Bavaria, Germany.

2 ARCHITECTURE

The objective of the proposed architecture is to stabilize the grid and its *Power Quality* (PQ). In order to monitor the PQ, it is essential to measure voltage, current, frequency, harmonic distortion and waveform interferences at different points of the grid. In our architecture, shown in Figure 1, the power quality is indicated by *Key Performance Indicators* (KPIs), e.g. the voltage level at certain points of the grid or overloading of grid elements such as the transformers. These KPI classes are measured/computed in real-time based on measured values from measurement devices that are installed at different locations in the low voltage grid (red points inside the grid in Figure 1).

In order to support grid stability, the proposed architecture needs to respond to different PQ-issues in real-time and a high resolution data stream is required, e.g. in 3 seconds resolution. Hence, an event-driven architecture (Apache KAFKA[1] in our case) is proposed, which triggers PQ-events in the grid, e.g. over- or undervoltage,

[1]https://kafka.apache.org/

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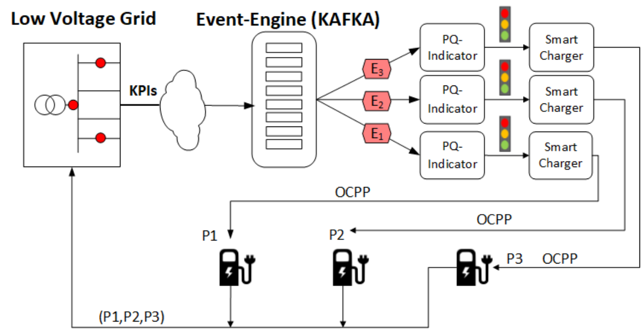

Figure 1: Schematic Smart Charging Architecture.

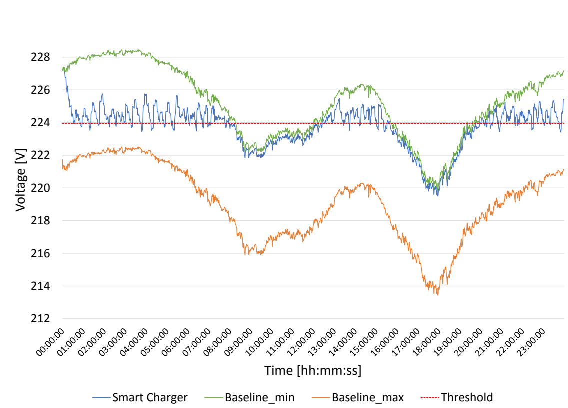

Figure 2: Voltage level at the critical point in the Bavarian grid during a whole day. The orange line and the green line represent the baseline scenarios, while the blue line shows the voltage level when all charging stations are controlled by our smart charging algorithm. The dotted red line is the lowest allowed voltage level for the algorithm.

that require reactions from controllable loads, e.g. the charging stations.

We propose a component, called *PQ-Indicator*, that runs on the charging station level and indicates the grid status with regard to the charging capability based on different values of KPI classes. Its output, called *PQ-Indic*, is defined within the range $[-1, 1]$. The minimum (-1) corresponds to *stopping the charging process completely*, whereas (+1) means *using the maximum capacity of the CS*. Furthermore, the design of the PQ-Indicator adopts the traffic light model with three colors (red, yellow and green) based on values range of the PQ-Indic. In addition to the PQ-Indic value, the different colors classify the electric vehicle charging capability of the power grid.

The output of the PQ-indicator is used by a component called *Smart Charger* (SC), whose responsibility is to apply a smooth or drastic change in the used charging capacity depending on the grids' need. The logic of the Smart Charger is based upon a *Finite State Machine* (FSM), which stores the last PQ-Indic and, hence, guarantees a smooth change of the charging stations' demand. The FSM allows to define different transition actions that depend on the last grid status. Each transition reveals the new charging power of the charging station, while the change of the charging power can be linear or polynomial way, depending on the color of the PQ-Indic. The capacity limitation is transmitted to the CS using the *Open Charge Point Protocol* (OCPP)[2] protocol in version 2.0.

3 EVALUATION

For the evaluation scenarios, we use the co-simulation framework *AIT Lablink* [5]. With Lablink it is possible to replace software simulation components by different PHIL equipment in the laboratory, e.g. a hardware charging station with Type 2 charging connector or either a real or an emulated EV based on a *Resistor - Inductor - Capacitor* (RLC) load model. The smart charging evaluation is carried out on a simulation of a realistic low voltage, which is located in a small city in Bavaria. This low voltage network connects 22 households, 21 industries, three PV systems and four charging stations to a transformer using 64 cables. The farthest connection point has a overall cable length of 1230 meters to the transformer and is defined as the critical node in terms of voltage.

The result of our smart charging algorithm is compared against two baseline scenarios: *(I) All charging stations charge for the whole time period with their maximum charging power* and *(II) No charging station charges at all*. Two criteria are used to evaluate the impact of our smart charging algorithm on the power quality of grid using simulation: the voltage level at the critical point of the grid and the loading of the transformer. In the simulation all four charging stations are equipped with the Smart Charger and the critical voltage level is configured to (224 V).

In this work and because of size constraint, we show only the results regarding to the voltage level criteria. Hence, as can be seen in Figure 2, the Smart Chargers change their charging power rate every time when the voltage crosses the predefined threshold during the early morning, late evening and short time in the afternoon between 13:00 and 15:30. In order to not worsen the grid situation during the peak times, where the base load is already high enough to produce undesired voltage levels, the Smart Charger reduces their charging power to the minimum.

4 CONCLUSION AND FUTURE WORK

In this work, a smart charging architecture based on real-time data stream for triggering events in the grid is presented, The architecture shows the ability to drastically increase the quality of power with regard to the voltage level and loading of the transformer by controlling the active power used by the charging stations.

In future work, we investigate fairness among charging processes, integration of Vehicle-2-Grid operation and a further evaluation of the proposed architecture.

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[2]http://www.openchargealliance.org/

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