Fair Charging Service Allocation for Electric Vehicles in the Power Distribution Grid

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ABSTRACT

The increasing battery capacity of electric vehicles allows longer driving distances, but also requires longer charging times, so that European standard Schuko electricity socket-outlets at households (max. 3.7 kW) are not suitable for full charge cycles over night. Private (semi-) fast wall-boxes often require enhancement of the power distribution system or otherwise partial overloading can occur in case electric vehicles charge simultaneously at the same area. This work proposes a dynamically weighted fair queuing algorithm, which can be applied to radial power distribution grids, for fairly allocating the available charging power capacity to ongoing charging processes. In contrast to other solutions, the fairness is based on the whole charging service, considering both, the required energy and the availability of the electric vehicle. The proposed algorithm is compared by simulation with statically weighted fair queuing, earliest deadline first and first come first serve charging power capacity allocation.

CCS CONCEPTS

• **Hardware** → **Smart grid**; • **Networks** → Network resources allocation.

KEYWORDS

dynamically weighted fair queuing, electric vehicle charging, smart grid, fair charging service allocation

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1 INTRODUCTION

Electric Vehicles (EVs) are seen as one of the key means to meet the reduction of global greenhouse gas emission and air pollution in the transportation sector by 2050 according to the European Transport Roadmap [4], especially with the increasing use of renewable energies. The increasing number of EVs and their battery storage capacity will likely create a high pressure on nowadays power distribution grids in the future. In order to supply all customers with a fair charging service, either the grid must be enhanced, or an intelligent charging capacity allocation mechanism needs to be established. Such strategies allow power distribution system operators to control charging processes remotely, e.g., using the *Open Charge Point Protocol* (OCPP)[1] and the ISO 15118 standard. This work addresses distributed decentralized EV charging in residential areas on standard European three phase circuits, at which installed wall-boxes can charge with up to 22 kW (32 A). It is assumed that the charging capacity of each vehicle during the charging process can be controlled in discrete steps, similar as specified in IEC 61851-1. In the context of this work, electricity (in the form of available grid capacity) is seen as a limited resource that needs to be fairly distributed among several end consumers in the power grid analogous to packetised communication networks.

Solutions from literature solve optimization problems and guarantee proportional fairness, not respecting other charging service factors such as the availability of the electric vehicles [1, 2, 8]. Other authors propose round-robin, first come first serve, first depart first serve or weighted fair queuing scheduling for discrete time slot allocation [3, 12, 13] or price-based solutions [6, 11]. This work defines fairness for the whole charging service allocation including the available charge time and the remaining state of charge of the EV. Furthermore, not only temporal charging slot allocation (with fixed charging rates) is modeled, but the charging capacity during each time slot is distributed to the EVs as well.

2 ALGORITHM

The algorithm proposed in this work is based on the weighted fair queuing scheduling known from the communication domain [9]. For each packet flow that passes a shared link, a separate queue with a specific weight is maintained. Whenever the link has free capacity, packets from these queues are scheduled according to their virtual finish time, which is calculated by the bandwidth, the size of the packet, the weight of the queue and the sum of all weights. In this work, each EV (represented by a packet flow) requests its required amount of packets (e.g. each equal to 1 A power capacity) to the *Scheduling Unit* (SU), which is placed at the supplying (shared) link. Instead of determining one fixed weight for each flow, the weights dynamically change over time and consider two aspects: *(i) remaining time to charge* and *(ii) the battery state of charge.* On the one hand, EVs with near departure time need to be scheduled first, in order to have the chance to finish their charging process in time. On the other hand, EVs that still need to charge a higher amount of energy must be prioritized, because their remaining charging process takes longer compared to others in this area. The

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

sum of power capacities of the delivered packets form the charging power capacity of the EV and the scheduling algorithm is repeated for each time slot.

Determining the available bandwidth of the shared link can be done by measuring relevant parts of the distribution grid and from that infer the available charging capacity of the next time slot e.g. using short-term forecasts. In order to map the packet scheduling on top of the radial power distribution grids, one SU is (logically) placed at each shared link and is responsible to distribute the available capacity among all connected EVs. The algorithm is applied hierarchically to the radial power grid and the communication effort scales linearly with the number of involved SUs and EVs.

3 EVALUATION

For a most realistic evaluation, flexibility patterns of EVs are extracted from travel data of a mobility survey in Germany [5] and the distribution grid simulation is carried out on a realistic low voltage grid in a small town in Germany. This simulation is supplied by load profiles from BDEW[2] for small industries and shops and realistic 1-minute load profiles provided by Tjaden et al. [10]. Different penetration scenarios (one, two or three EVs per household connection) and maximum charging rates (slow: 6 A, medium: 16 A and fast 32 A) at the wall-boxes are defined within the co-simulation environment Mosaik (version 2.4.0).

Compared against statically *Weighted Fair Queuing* (WFQ) (similar to [12] with weights determined by the required energy only), *First Come First Serve* (FCFS) and *Earliest Deadline First* (EDF), the proposed *Dynamically Weighted Fair Queuing* (DWFQ) algorithm obviously has the smallest finish ratio over 20 independent simulation runs with different EV demand profiles, because nearly finished charging processes receive lower weights. Nevertheless, DWFQ outperforms FCFS and WFQ by 3% at 350A transformer limitation in the *Quality of Experience* (QoE) [7], which is based on the standard deviation of the SoC at departure time of the EVs. Only EDF scheduling performs better in this respect, but as can be seen in Figure 2, the charging is done basically in sequential order, whereas DWFQ provides at least a small share of the available power capacity at any time the EV is available. Compared to EDF, mistreating the DWFQ scheduling is by design less effective and EVs that need to leave far ahead of the planned departure time can still obtained a fair portion of the available charging power. At 80% before planned departure time, the QoE of DWFQ is up to 7% better compared to EDF scheduling.

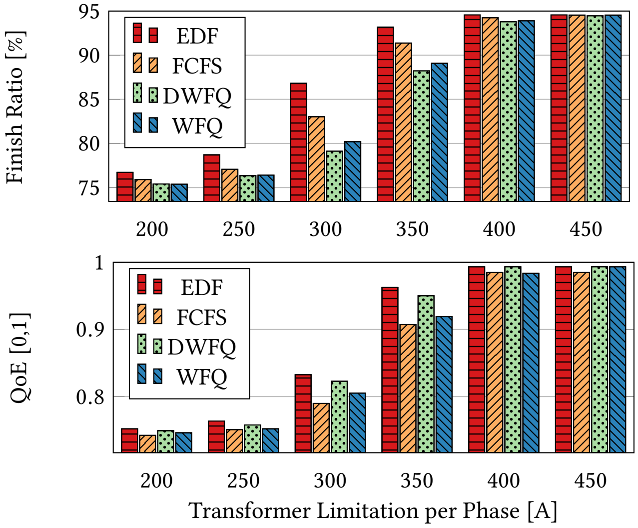
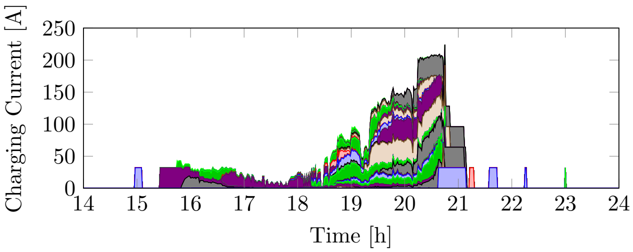
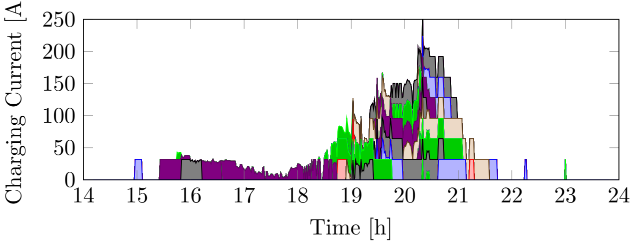


Figure 1: Ratio of finished charging services and quality of experience with different transformer limitations in Scenario 2, fast charging (32 A).



(a) DWFQ: Charging processes are served during the whole EV availablity.



(b) EDF: Charging processes are only serverd according to their deadline resulting in priorized charging blocks.

Figure 2: Charging service allocation during the peak EV demand hours. Scenario 3, (32 A) with transformer limitation of 350 A per phase.

4 CONCLUSION AND FUTURE WORK

In this work, a dynamically weighted fair queuing algorithm is proposed, which allocates the available charging capacity fairly to the connected electric vehicles in the low voltage grid considering both, the remaining charging time and the required energy.

In future work, capacity limitation and reactive power compensation can be used for voltage level control, while not discriminating charging processes at locations with low voltage levels. Furthermore, by dynamically changing the transformer limitations all subordinated electric vehicle can be used to fairly react on market prices or provide ancillary services to the grid.

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[2] Bundesverband für Energie- und Wasserwirtschaft (English: Federal Association of Energy and Water Management)

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