A MULTI-AGENT BASED APPROACH FOR SIMULATING G2V AND V2G CHARGING STRATEGIES FOR LARGE ELECTRIC VEHICLE FLEETS

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ABSTRACT

A simulation environment consisting of different tools for simulating vehicle traffic, charging activities, power generation and the electrical network, was established. Temperature dependency of vehicle consumption and charging losses were implemented. Based on cumulative values of charging power from aggregated charging locations, defined power limits and power generation, a charging algorithm was developed, which enables the allocation of charging power to individual vehicles as a function of their state-of-charge. The simulation environment including the charging controller provides a platform for testing various charging algorithms with multi-agent based approaches.

INTRODUCTION

Battery electric vehicles (BEVs) powered by energy from renewable energy resources are commonly seen as one of the alternatives to reduce greenhouse gas emissions (GHG) and oil dependency in the transport sector. The present technical specifications and range of electric vehicles seems to be capable of fulfilling the need of a high percentage of customers under normal circumstances (95% of travelled distances by car are below 50km) [1]. A variety of roll-out scenarios and plans are picturing the future fleet of electric vehicles [2], standards and specifications of EV technology and charging infrastructure. Besides these technical changes in the drive-train, communication technologies are pushing changes in the mobility patterns to the concept of multi-modal mobility [3].

With 25% of all travelled distances, one of the main initiators of people and vehicle movement is employment [4]. During the last years, the number of employees who had to commute to there working place was rising constantly. In 2009 in Austria more than 90% of all people with paid work were either in-, out- or intra-commuters, most of them travelling by car from rural to urban areas [5]. Rising financial regulation of limited parking space in cities increase the attractiveness of vehicle drivers in using Park & Ride (P&R) multi-story car parks combined with other transportation means. Future P&R multi-story car parks might also be uses by drivers of BEVs, therefor appropriate infrastructure has to be provided to ensure a sufficient state-of-charge for the next journey.

For utilizing the BEV high potential of reducing GHG emissions, charging energy should mainly be provided from renewable sources. The unpredictable nature of renewable energy resources (like wind power or photovoltaic) lead to a fluctuant generation of electrical energy.

The aim of the work in this paper is to develop an appropriate simulation environment and charging strategy for optimizing the charging demand from BEVs along within power limits and fluctuating renewable energy generation. The controller should allow aggregation on location level (e.g. one location represents a multi-story car park consisting of a high number of individual charging stations) and regulate the charging power of each individual charging station by defined parameters.

SIMULATION ENVIRONMENT

The simulation environment is based on [6] and [7] can be classified in different modules, the traffic simulation, the electric vehicle simulation and the electric power system simulation. For each of these modules different tools were used and assembled to a simulation chain. The charge controller represents an additional module which is embedded in EVSim. Figure 1 provides an overview of the simulation environment.

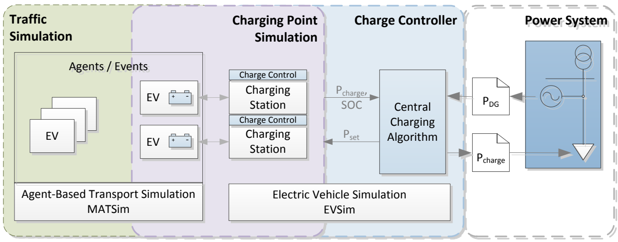

Figure 1 - Simulation Environment Overview

Traffic Simulation

As tool for agent-based transport simulation MATSim [8] was chosen. For running simulations in MATSim, it is necessary to prepare a specific street network file and agent plans. The street network file can be generated with the tool OSMOSIS [9] and data from open street map (OSM) [10]. Agent plans have to contain at least the information for the type of transportation (e.g. car), event times, and the coordinates of the origin and destination locations. As input for Agent plans, traffic surveys or statistical mobility data can be used. The output of MATSim are agent plans containing IDs, locations, distances and durations which represent the optimum of the whole simulated traffic system.

Electric Vehicle and Charging Station Simulation

The aim of the electric vehicle simulation tool “EVSim” is to dynamically simulate the charging and discharging of the battery during the trips and determine the energy demand of EVs. Trip data can be taken from travel survey data or other sources. Beside the battery discharging and charging simulation during the trip, the protocols for connection, authentication and disconnection with the charging points are implemented. The inputs for the simulation are: configuration of the EV and battery types, locations of the charging points and a list of event for each agent (e.g. departure, move, arrival and stand-by) with the corresponding distances driven. Events can be created manually or via a format conversion from MATSim's output of optimized agent plans. The battery model included in the EV model can be changed according to the needed accuracy and time scale of the simulation (e.g. temperature dependency, constant current - constant voltage charging sequence). The simulation of discharging during the driving phase is simplified by the measured average consumption. An exact consumption model would include the driving behaviour and street parameters like velocity or height profiles. This could be achieved by dynamic coupling to a traffic simulation like MATSim. EVSim is capable of performing offline and real-time simulation and provides an OPC interface which allows connecting and validating various charging control algorithms. A description of the dynamic simulation capabilities and the co-simulation environment and applications can be found in [6].

BEV and charging infrastructure models

To enable simulation vehicle fleets consisting of a variety of different BEV models each simulated Agent gets an allocated vehicle, defined by its type-id. Table 1 shows the parameters which can be defined per vehicle type.

Table 1 - BEV technical specification variables

Variables	Description
type_id	EV type id
EV_type	e.g. Average E-Car
PlugType	e.g. Mennekes 16A
max_I	Max. Amperage per phase
phases	1 or 3 phase charging
voltage	e.g. 230V
battery_type	Battery type ID

The vehicle definition is extended by the specifications of its battery. Diverse vehicles can use the same type of battery. Table 2 provides an overview of some variables of the battery specifications.

Table 2 - Battery technical specification variables

Variables	Description
Id	Battery type ID
type	e.g. Li-Ion
capacity	Battery capacity (e.g. 23 kWh)
range	Range with full battery in 20°C conditions (e.g. 150 km)
Consumption performance	Temperature dependent function
Charger performance	Temperature dependent function

EVSim allows the aggregation of charging stations by their location. The simulation can contain any number of locations. Each location (e.g. a Multi-story car park) can contain any number of charging stations. Table 3 shows the configuration values of a charging station. The values “plugtype” and “phases” represent the allowed maximum and are downwardly compatible. For e.g. a charging station configured with phases 3 also accepts BEVs which can only charge with one phase.

Table 3 - Charging station configuration values

Variable	Description
Location id	Location of the charging station/s
Charging station id	Individual id of the charging station
plugtype	Allowed plug type (e.g. Mennekes 16A)
phases	Allowed number of phases

Temperature Dependency

Due to different environmental temperatures the range of BEVs can be reduced by 50% from its nominal value. Based on measured data from commercially available BEVs [1] temperature dependency of energy consumption and charging losses were modeled and implemented in EVSim. Figure 2 shows an example of values (consumption and charging efficiency) for a temperature range from -20°C to +30°C. For different vehicle type models, individual curves for consumption and losses were created.

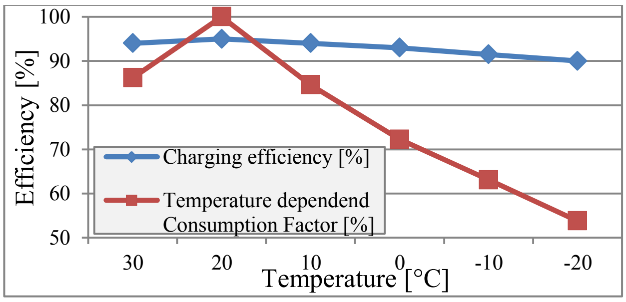

Figure 2 – Example for temperature dependency of consumption and charging efficiency

During each simulation time-step, energy consumption and losses are calculated for each individual vehicle.

Electrical Power Grid Simulation

In this work, the aim of the electrical power grid simulation is to provide signals for the optimization algorithm for decision making if or if not a vehicle is allowed to charge. These signals are, depending on the specific charging strategy, based on supply or demand data of electrical energy. For example energy generation data from wind farms, photovoltaic, or energy consumption time lines.

G2V AND V2G CHARGING ALGORITHMS

For simulation controlled charging strategies, EVSim was extended with a charging controller module.

Uncontrolled Charging

The uncontrolled charging scenario is following the opportunity charging approach. This means that the charging process of batteries from BEVs is starting whenever a car stops and connects at a charging point independent from its actual SOC. It is assumed that charging infrastructure is available at every parking location and BEV users connect their cars at every stop. The total charging demand is given with:

$$P_{charge\ SUM} = \sum_{n=1}^{Locations} \sum_{i=1}^{CS} P_{charge}(n,i)$$

Controlled Charging: Grid-to-Vehicle (G2V)

The following equations specify an example for a generation profile following charging algorithm:
BEVs with a SOC below a certain minimum level (SOC_{min}) will be not curtailed:

$$\forall EV^i\big|_{SOC<SOCmin} \rightarrow P_{chrg\ SET} = P_{chrg\ MAX}$$

Thus only the BEVs with SOC > SOC_{min} are available for the generation optimized controlled charging, all EVs with SOC < *SOCmin* reduce the available power:

$$\Delta P = P_G - \sum P_{chrg}\Big|_{SOC<SOCmin}$$

If there is power available it can be distributed among the remaining charging stations (SOC > *SOCmin*), starting with the CS with the smallest SOC:

$$\forall BEV_i|_{SOC>SOCmin}: BEV_i' = sort\ ascending\ \{SOC\}$$

$$\forall CS_i'|_{SOC>SOCmin}: P_{chrg}^i = \min(P_{chrg\ MAX}, \Delta P_t)$$

$$\Delta P_{t+1} = \Delta P_t - P_{chrg}^i(i)$$

Controlled Charging: Vehicle-to-Grid (V2G)

The Vehicle to Grid concept describes the capability of grid connected electric vehicles to either act as consumer or as producer of electric energy. BEVs with a SOC higher than a certain level SOC_{V2G} are available for discharging their stored energy and charging other BEVs. A threshold ensures the discharging between:

$$\text{V2G: } SOC_{V2G,high} > SOC_{VSG} > SOC_{V2G,low}$$

$$P_{discharge\ V2G} = \sum_{i=1}^{CS} \begin{cases} 0, & SOC < SOC_{V2G,low} \\ P_{dischrg}^i, & SOC \geq SOC_{V2G,high} \end{cases}$$

Thus the total demand needed from the grid can be written as:

$$P_{charge\ SUM} - P_G - P_{discharge,V2G} = P_{Grid}$$

As shown in Figure 3 the basic V2G approach in this paper is working SOC based. BEVs with SOC above 85% are available for V2G to discharge till they reach a SOC level of 75%. The V2G algorithm described in this paper is to charge BEVs with SOC below 50% with renewable energy from already charged EVs.

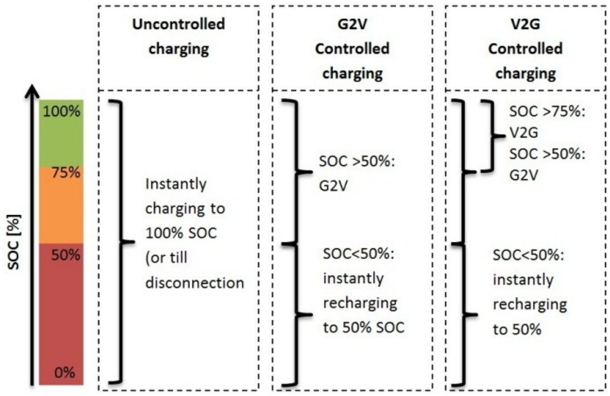

Figure 3 – Example SOC levels for controlled G2V and V2G charging

SIMULATION EXAMPLE

The following use-case should provide an example how this charging controller works.

Table 4 - Scenario definiton

Number of BEVs	Battery capacity	BEV max. charging power	Power limit	PV P_{peak}
306	23 kWh	11 kW	400kW	100kW

Table 4 shows the main parameters for this use-case. 306 BEVs around a rural area, driving 80 km in average per day, are performing end-of-travel-day charging. This means, the energy consumption from all trips during the day has to be recharged at home. Uncontrolled charging is compared to controlled charging. For controlled charging a maximum power consumption (from grid) of 400 kW plus generation from the PV-system is set as limit.

Table 5 provides an overview of the total energy consumption of all BEV. The coverage during a summer and winter day is outlined. In summer a small amount of energy is fed back to the power grid.

Table 5 - Energy analysis

Scenario	Charged Energy (total) [kWh]	Self-coverage from PV	Energy from Power Grid	Delivery to Power Grid
Winter	5618	6%	94%	0%
Summer	4200	15%	85%	1%

Figure 4 shows a comparison from uncontrolled and controlled charging. It is shown that during this day the power limit (power from grid) is not reached and the peak during the day compared to uncontrolled charging is cut by 50%

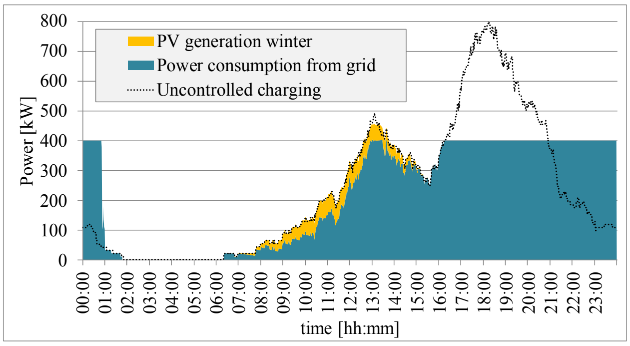

Figure 4 - Controlled vs. uncontrolled charging during a day in winter

CONCLUSIONS

The outlined simulation chain and multi-agent based approach provides a flexible modular platform for the implementation and further development of charging algorithms.
SOC based charging control favors vehicles with low battery rest-capacity and ensures their recharging. This decreases the number of vehicles which run out of energy during there next trip and might increases the level of acceptance.
The composition and performance of the simulation chain and charging algorithm allow the simulation of use-cases containing thousands of individual vehicles.

Outlook

For taking this charging algorithm to more sophisticated levels, it is conceivable to extend it with further considered variables and functions. For simulating specific use-cases containing business cases, the consideration of service-level-agreements (SLA) would be advantageous.
Optimization amongst individual locations (with diverse objectives per location) would allow simulations of large geographical areas with diverging needs of optimization.
For improving the interconnection with a power simulation tool as outlined in Figure 1, calculated values per simulation time-step from the power system could be used as input values for EVSim. This would for example enable the demonstration of rebound effects from charging EVs if drops in the voltage of the individual supply lines are taken into account.

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