APPLYING SIMPLE DATA-DRIVEN CONTROL ALGORITHMS IN LOW-VOLTAGE GRIDS WITH FLEXIBILITY PROVIDED BY ELECTRIC VEHICLES FOR GRID-ORIENTED CONTROL

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1 Topic

To reduce emission of greenhouse gas, energy transition in transport section is necessary. The simultaneous charging processes of large number of electric vehicles (EV) could result in grid congestions in distribution grids (DG). In Germany, the distribution system operators (DSO) are allowed to limit charging power of EV charging points in private households with the purpose of ensuring reliable electricity supply [1], which is also called the grid-oriented control. However, this control schema faces some challenges in practice. First, grid state data collected by smart meters (SM) are sent only once a day to DSO in the default setting [2]. And the data must be anonymized due to data privacy protection [3]. As a result, it is impossible for DSO to have a full observation of the real-time state of the charging points. In addition, exact digital models of low-voltage (LV) grids are not available for many DSO. The facts mentioned before lead to high uncertainty in the grid-oriented control.

This work uses data-driven control algorithms intending to bring critical grid states caused by EV charging processes back to allowed operating range. The proposed methods use only real-time system feedbacks to control grid states without any knowledge about power consumption of underlying private households and power system models. In contrast to complicated control models based on artificial intelligent (AI), the purpose of this work is to develop simple controllers with interpretable structures and simple algorithms. Since the proposed easy-to-use methods fit the controller parameters using only a few online data from the most recent periods, the sudden change of LV grid dynamic caused by stochastic factors can be detected easier. Additionally, the small number of parameters in these control algorithms reduces significantly the computational complexity and the costs of large-scale implementation. The research question is: what are the performances of simple data-driven control algorithms using only real-time system feedbacks in the grid-oriented control? The aim of this work is not to conduct a comprehensive comparison of numerous methods, but to implement some promising methods that are suitable for our case, and then evaluate the performances as a preliminary study.

2 Method

The framework of the grid-oriented control is shown in figure 1. As a curative measure to ensure grid security, the DSO obtain real-time LV grid states collected from measurement devices located at some key positions, such as transformers and heads of LV feeders. Once critical grid states are identified through state estimation, control decisions must be made with the purpose of limiting charging power of underlying EV in this grid area. After implementation of the control signals in private households using smart meter gateway, local grid congestions should be relieved. The objective of the data-driven control algorithms is to find the solution of the optimization problem described in the following equation:

$$a_t^{aft*} = arg \min_{a_t^{aft}} \left| S_t^{aft} - \tilde{S}_t^{aft} \right| \quad (1)$$

where $\tilde{S}_t^{aft}$ represents the desired grid state after implementation of the power limit signal, and S_t^{aft} is the corresponding actual grid state. a_t^{aft} represents the deployed control signal estimated by the control algorithm at time step t. Two kinds of data-driven control methods based only on online data are implemented and evaluated in the grid-oriented control: model-free adaptive control (MFAC) and simultaneous perturbation stochastic approximation-based control (SPSA). The MFAC uses real-time system feedbacks to build a dynamic linearization model, which estimates the output through pseudo partial derivative at each time step. The SPSA has a fixed controller structure, but the parameters are optimized through setting stochastic perturbations and observing closed-loop measurements.

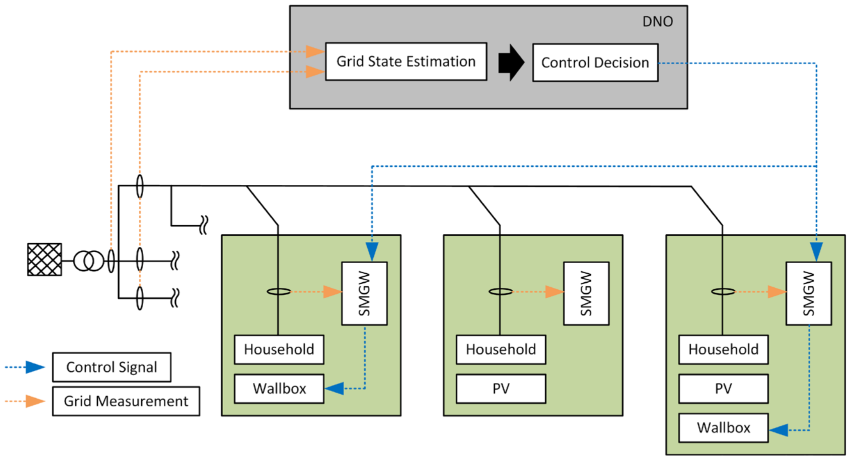

Figure 1: Framework of the grid-oriented control in LV grid with controllable charging points

Reference grid models are used to build representative LV grids for further tests. Additionally, the real-world power consumption profiles of private households collected from SM are used to generate scenarios for the case study. Through steady-state power flow analysis at each time step, the grid state data measured at some key positions can be obtained by means of simulation. At the beginning, all parameters of the controllers are randomly initialized. Using online feedbacks of the target LV grid, the parameters are updated iteratively based on the corresponding control algorithms. The performances of the data-driven control methods are evaluated in the following two main perspectives: eliminate deteced overloads of local LV grids without excessive limitations on EV charging power and withdraw applied power limits without inducing new overloads.

3 Outlook

The main purpose of this paper is applying simple data-driven control algorithms in LV grids for the grid-oriented control, even though digital grid models and real-time grid states collected from SM are not available. The tested methods can be easily implemented in praxis due to the compact structures and low computational costs. However, the challenge is not limited to the grid observability. From the view of control theory, the LV grids do not belong to linear time-invariant system. The plug-in and plug-out processes of EV change the dynamic characters of LV grids constantly. In addition, the change of power consumptions in households and the fluctuation of power injection of photovoltaics (PV) are mainly determined by extraneous factors rather than the control signals. As a result, disturbances could dominate the measured grid state data, and the changes of grid states might be difficult to understand. These challenges prevent the convergence of the simple data-driven control algorithms and the stability of the control performances.

Further works should pay more attention to utilize AI-based methods aiming to identify hidden patterns from offline data. If the relationship between the grid measurement data and the change of system dynamic due to EV plug-in and plug-out or the change of disturbances caused by weather can be learned by AI-models, the control performance could be improved significantly.

References

[1] Bundesnetzagentur, „BK6-22-300 Beschluss,“ 2023.

[2] Bundesamt für Justiz, „§ 34 Messstellenbetriebsgesetz - MsbG“.

[3] Bundesamt für Justiz, „§ 52 Messstellenbetriebsgesetz - MsbG“.