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Electric Vehicle integration schemes

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Introduction

Electric Vehicles (EVs) will play an important role in the future of transportation. EVs - similarly to other Distributed Energy Resources (DER) such as small photovoltaic units - also modify consumption patterns to an extent where this can and, in many cases, will lead to problematic operating conditions of the system if we do not consider appropriate countermeasures. Such countermeasures are means to resolve operational issues by improving the physical infrastructure or the way one operates the system.

Methods

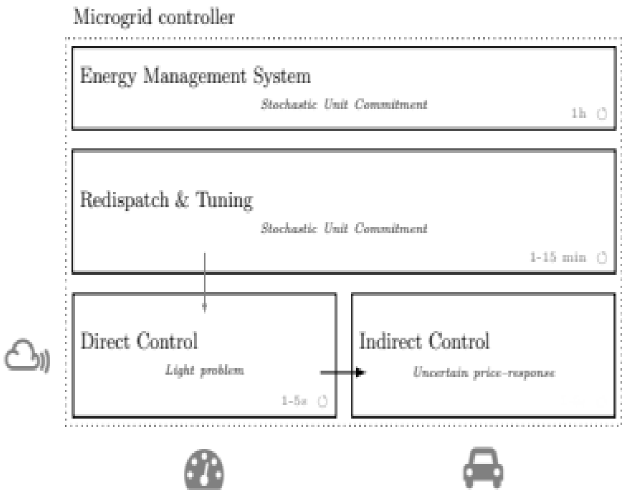
The cyber-physical domain must consider operational decision-making that accounts for these challenges. It may sound trivial, but it is far from it: One can always think of some resolution that caters to one desired outcome, but to satisfy a wide range of such expectations is a more difficult endeavor. For example, curtailment of a critically loaded node in the distribution system may be possible, but in general, this is not a desirable decision. Also, investments into the distribution infrastructure are possible but are expensive to an extent that we cannot consider this as a viable solution at large. One must find beneficial trade-offs considering these and other constraints when aiming towards a successful integration of EVs into the distribution system.

Such trade-offs one can discover when considering both the physical infrastructure and operational decision-making. This is the aforementioned cyber-physical domain. It entails layers of decision-making algorithms that provide decisions in complex operational spaces. One layer may include an algorithm that sets the charging current for an EV and in this way directly controls the charging process. Here, the EV driver plugged the EV and started the charging process with the goal of having a sufficiently replenished battery in a desirable time. The EV driver or more generally, the EV operator, is the operating entity and thus decides when and how much to charge it. This is important when the main purpose of an EV is to service mobility needs. However, another purpose of EVs with enabled vehicle-to-grid technology (V2G) can be to provide flexibility to the grid provided that the EV owner agrees to this use case. By offering flexibility the EV contributes to the compensation of bottlenecks in the system and for doing so, the distribution system operator (DSO) remunerates the EV owner. This way, this use case becomes economically viable to the EV operator.

An EV with bi-directional charge flows is a prosumer and offers two degrees of freedom in regard to charge flow directionality. Other degrees of freedom exist, such as ramping capability or duration of sustained peak power flows. The need for flexibility is time-varying and consequently, the remuneration for flexibility provision should be as well. Through this, the monetary compensation informs the EV operator of the flexibility demand. Known as indirect control, this operating scheme retains the flexibility of the EV operator and therefore the main purpose of the EV of servicing mobility needs. Yet, this control scheme is capable of leveraging a desirable contribution of flexibility from the demand side and prosumers such as an EV with V2G capabilities. Similarly as for direct control, one may cast indirect control as a feedback control problem or as a predictive control problem: Rather than considering a remuneration based on the current flexibility need, we may consider an economic reward scheme aiming to proactively steer the EV operator using a price-signal.

For this setting, one can design cyber-physical systems in different ways, one of which we discuss here considering publications [1] and [2]. [1] outlines the design of an EV aggregation scheme treating uncertainty via a scenario-based approach and is consequently formulated as a Stochastic Program (SP).

Using aggregation, a single EV otherwise too small to participate in conventional energy markets can enter these via the aggregated bid. Hereby, the aggregator as entity performing aggregation offers the aggregated system's capabilities to markets.



The SP considers a probabilistic EV park model, assuming knowledge of the availability and State of Charge (SoC) of each EV. The method considers battery degradation costs but disregards other constraints such as nominal charge flow limits or, related to this, the battery temperature. Neglecting other technical details here, the method yields a charge flow schedule on a per-EV basis which we can use as an operational reference for the approach outlined in [2]. [2] considers a control hierarchy in which an approach such as the one outlined in [1] can form the master decision-making routine, see the illustration in the top right. This hierarchy consists here of the aforementioned SP as Energy Management System, a redispatch and tuning layer, as well as the aforementioned direct control and indirect control modules in the real-time layer. These layers and modules form a "microgrid controller" – a controller for a sub-set of the distribution system. From top to bottom, computational complexity reduces while the lowermost layers are sampled closest to the real-time system.

In [2] we model a price-response of the EV linearly for simulation purposes, disregarding rebound effects. We offer designed price-offers to the price-responsive EV for the desired response in order to incentivize a behavior desirable from the indirect controller's perspective. The latter is informed by the controller's objective function as well as the reference provided by other parts of the hierarchy. Notice that while the illustration indicates a reference from the direct control module, these references can in principle be time-varying depending on operational requirements. One could uncover a prioritization of control reference candidates in this scheme using multi-objective optimization. The price offer should entail a remuneration as discussed on the previous page, which should compensate the EV operator in such a way that participation in this prosumer response scheme is incentivized.

Conclusion

To summarize, EVs can be both an issue and a solution considering the limitations of the distribution system of today. Stochastic models, optimization methods, and control theory form a toolbox from which one can design control hierarchies: operational constructs that enable EV integration such as to benefit the distribution system and stakeholders, including the EV operators themselves.

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Papers

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