Algorithms for Electric Vehicle Scheduling in Smart Distribution Networks

ABSTRACT

The adoption of electric vehicles (EVs) has taken a quick pace. This can be credited to reduction in battery costs and improvement in charging infrastructure, and also in part to shift of consumer choices towards environment-friendly products. As commonly established, rapid increase in EVs will bring several challenges to power grid operations. Few of those challenges being increased demand peaks, intermittency of charging loads, voltage unbalance and voltage deviations in power network, and expensive upgrade required for fast charging infrastructure. In particular, uncoordinated charging of EVs would bring unpredictability in power system operations thereby leading to financial losses to the utility. On the contrary, smart control of EV chargers can curtail, shift, or throttle charging demand to reach optimal grid operation. Such intelligent charging, through application programming interfaces (APIs), can be used to shape load profiles of charging stations. Moreover, charging stations with integrated distributed energy resources (DER) can also become prosumers with surplus energy for trading with peers. Every EV user would also have distinct preferences on energy prices, permitted rate of charging or discharging, battery degradation, and information exchange. Further, smart charging algorithm for EVs can suffer from scaling issues where sudden arrival or departure of EVs can bring about additional burden of algorithmic update with new-found information. It is also promptly assumed that EVs are always responsive and accept the smart charging signals with no fault. In practice, due to random EV mobility, volatile battery charging characteristics or charging component failures, some EVs would be unable to accept the assigned charging signals dispatched to them. Also, the use of DERs for charging purposes can induce demand-generation mismatch owing to intermittency of photovoltaic (PV) or wind generation plants.

This thesis aims to provide operational and short-term planning of EV energy management to solve the problems stated above, while covering micro-economic aspects, particularly related to the interactions between EV fleet managers, i.e. EV aggregators (EVAs) and EV owners for finalizing quantity and price of power trade. In particular, social welfare maximization charging

strategies for fleets of EVs are proposed, which ease grid operation using vehicle to grid (V2G) support from EVs. Further, uncertainty handling optimization techniques are presented to hedge against any randomness in grid loads or DER generation. In particular, using recursive optimization integrated with robust models of EV-PV uncertainties, the proposed methods in this thesis ensure least welfare loss to EVs or EVAs under a range of unpredictable load-generation scenarios. Moreover, a framework of parallel-operating and fast converging distributed algorithms is also proposed which aims at increased EV user-privacy, improved convergence properties and optimal operation under communication disruptions between EVAs and EVs. Under the proposed methods, PV utilization is maximized by capturing the time correlation of EV charging demands and available PV generation. Moreover, formulation of a peer-to-peer (P2P) market is developed, where EVAs can transact their surplus DER generation to a competitively matched peer considering power loss sensitivity of a low-voltage (LV) distribution network. Finally, this thesis develops privacy preservation methods to mask any coordination signals to be exchanged over decentralized demand scheduling algorithms, thereby encouraging improved EV user participation in ancillary service demand response (DR) programs.

Various numerical simulations, run for multiple EVAs under CIGRE LV distribution network, show that the proposed methods exhibit low network losses under constrained EV charging, mitigate load unbalance and reduce demand peaks using V2G action, while reduce sub-optimality due to uncertain EV mobility and PV generation. Moreover, the proposed DR strategies help the EVA to proactively reduce financial cost of grid power procurement, while providing fair and rational payoffs based on the power extraction/injection of EVs combined with their battery degradation costs.