Probabilistic Electric Vehicle Charging Optimized With Genetic Algorithms and a Two-Stage Sampling Scheme

Stephan Hutterer, School of Informatics, Communication and Media, University of Applied Sciences Upper Austria, Hagenberg, Austria
Michael Affenzeller, School of Informatics, Communication and Media, University of Applied Sciences Upper Austria, Hagenberg, Austria

ABSTRACT

Probabilistic power flow studies represent essential challenges in nowadays power system operation and research. Here, especially the incorporation of intermittent supply plants with optimal control of dispatchable demand like electric vehicle charging power shows nondeterministic aspects. Using simulation-based optimization, such probabilistic and dynamic behavior can be fully integrated within the metaheuristic optimization process, yielding into a generic approach suitable for optimization in uncertain environments. A practical problem scenario is demonstrated that computes optimal charging schedules of a given electrified fleet in order to meet both power flow constraints of the distribution grid while satisfying vehicle-owners’ energy demand and considering stochastic supply of wind power plants. Since solution-evaluation through simulation is computational expensive, a new fitness-based sampling scheme will be proposed, that avoids unnecessary evaluations of less-performant solution candidates.

Keywords: Adaptive Sampling, Charging Control, Genetic Algorithms, Power System Optimization, Simulation-Based Optimization, Uncertainty

INTRODUCTION

Optimal integration of electric vehicles into modern power grids plays an essential role in future power system operation and control. Numerous investigations have been performed in order to identify optimal charging policies for meeting objectives like peak-shaving, optimization of power quality metrics or efficient usage of power from renewable sources. Especially this interaction of zero-emission supply plants and electrified vehicles is seen as central concern, since the usage of energy from renewables directly influences the reachable environmental benefit of electric vehicles (EV). Here, both the supply as well as the demand
side show nondeterministic behavior which has to be tackled in some way. Therefore, a simulation-based optimization approach will be demonstrated, that uses metaheuristic algorithms for finding optimal charging schedules of an EV fleet within a given system. This approach therefore considers both, the physical power grid as well as the individual electrified traffic through probabilistic simulation models, where all nondeterministic influences can be incorporated dynamically into the heuristic search process. Each solution candidate will be evaluated a sufficient number of times through simulation in order to increase the accuracy of the performance estimation within an uncertain environment. A fitness-based sampling approach will be introduced for decreasing computational effort of solution evaluation. The rest of the paper is organized as follows: next, basics of optimization issues within power grid operation will be discussed, introducing the problem of optimal electric vehicle charging control and its formulation. After showing the simulation-based optimization approach as being capable of handling the formulated problem, necessary simulation-models will be considered in detail. Beside modeling and simulation, optimization of the given problem will represent the core of this work. Thus, parameterization and adaptation of a suitable optimization algorithm will be discussed, introducing a novel approach for adaptive fitness-based sampling when evaluating a solution candidate in an uncertain environment. In the end, final conclusions can be drawn for rounding up the paper.

OPTIMIZATION IN POWER GRID ENGINEERING

General Problem Formulations

Optimization builds a fundament in today’s power grid operation, offering manifold applications for instance in power flow studies, maintenance scheduling or infrastructure planning. Here, substantiating findings in systems engineering and analysis as well as actual achievements in computer sciences enabled an established usage of optimization in today’s operation centers.

For stating the importance of optimization in power grid engineering, a brief overview should be stated now: economic dispatch has been stated in the early 1970’s. Being the basic optimization problem in power system engineering for later formulations, it tries to find an optimal configuration of generating units in a system in order to satisfy economic supply of power demand (Wood, 1996). This fundamental formulation is extended with additional constraints, yielding in the well known optimal power flow (OPF) problem. OPF aspires to meet optimality while incorporating power flow restrictions from a physical transmission/distribution grid point of view (Wood, 1996; Momoh, 2009). For this well-established optimization problem, various formulations exist for realizing different aspects of power grid security at the constraints side, while numerous investigations have been performed using different objective functions like the minimization of fuel costs, active power losses or environmental impacts (Momoh, 2009; Abido, 2003). Coming from the OPF, inclusion of additional aspects from generation plant operation leads to the next fundamental formulation, namely unit commitment. It incorporates OPF for finding an optimal commitment of available generation units, considering dynamic characteristics like up- and down ramps of possible generation capacity. Based on these essential formulations, further optimization applications have been identified within the last decades like infrastructure planning issues or computation of optimal maintenance schedules of supply, transmission or distribution equipment (Momoh, 2009; Werbos, 2011).

Coming from the so defined basic optimization applications in power grid engineering, actual developments can be stated, being mainly divided into two fields: on the one hand the deployment of novel optimization applications, which majorly gets pushed by the smart grid vision. On the other hand, the evolution of recent optimization methods like metaheuristic algorithms, which is mainly supported by the steady
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