Voltage-Based Autonomous Demand Side Management of Electric Vehicles

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Demand Side Management (DSM) is considered a mature concept to reduce and shift the power consumption of end-users. Thereby, the power supply is eased by reducing the stress on power system assets [1]. Beside distributed generation, energy efficiency and savings, load management constitutes one of the key measures of DSM. Within the framework of the Josef Ressel Centre for Applied Scientific Computing in Energy, Finance and Logistics, one subproject focused on decentralized, autonomous DSM (ADSM) of flexible loads [7] [9] [10]. The main objective was the implementation of an energy model library, which allows to simulate the transient behavior of real distribution grids under the influence of ADSM on energy storage systems.

Electric Vehicle (EV) charging loads pose new challenges to the operation of the electricity networks especially for the distribution grids. Uncoordinated EV charging load coincide with the normal peak demand of the base load and, therefore, increase the aggregated peak demand at the distribution transformers. These increased peak demands significantly stress the distribution systems causing severe voltage fluctuations and power quality problems [2].

However, the flexibility in charging time of EVs due to long standstill times offer the possibility of grid friendly EV integration through DSM. To do so, two general approaches exist 1) centralized DSM using direct load control with two-way communication and 2) local, autonomous DSM with unidirectional communication. In contrast, we analyzed a communication free autonomous charging management strategy for

EVs: a voltage dependent charging current control mechanism defined as dynamic I (U) control.

In I(U) control, the nodal voltage at the point of charging serves as the input to the controller. The controller output is the regulated charging power. When the nodal voltage drops below a reference voltage, the charging rate of the EV is reduced according to the characteristic curve shown in Fig. 1.

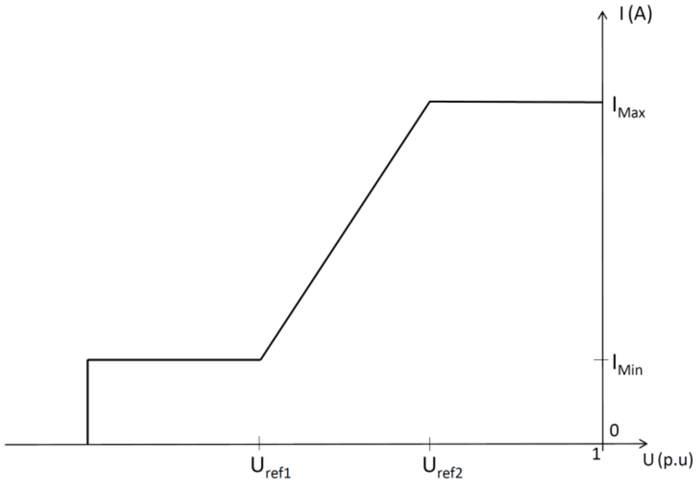

Fig. 1. Voltage dependent charging current characteristic curve.

We tested the proposed ADSM approach in a simulation setup using an in-house developed load flow simulation tool [8]. The software is based on the backward forward sweep method as proposed by Ghatak and Mukherjee [3]. As a testing case, real grid data for a weakly meshed distribution grid in Vorarlberg, Austria, is considered. The grid comprises two 630 kVA, 10/0.42 kV step down 3-phase transformers operating in parallel, 419 distribution lines, and 411 nodes. The data has been provided by the local system operator Vorarlberger Energienetze GmbH [4]. The residential loads are represented by measured smart meter data. Commercial and business related loads are represented by standard load profiles from the Austrian grid coordinator [5]. The driving profiles of the EVs are simulated based on the Austrian mobility survey “Österreich unterwegs 2013/2014” [6]. We conducted weekly simulations with a 15 min time resolution. Then we evaluated the performance of the proposed

ADSM approach by comparing to a benchmark case, in which the EVs are charged uncontrolled, exhibiting a 50% EV penetration.

Fig. 2 shows the voltage variation on a typical day at a node where an EV is present in the concerned distribution grid. The voltage violations due to uncontrolled EV charging can be successfully eliminated with the proposed I (U) controller. The number of recorded voltage violations improved to 48 from 165 in comparison to the benchmark case. It can be observed from further results that the voltage profile improves in all nodes, regardless of the presence of an EV at the specific node.

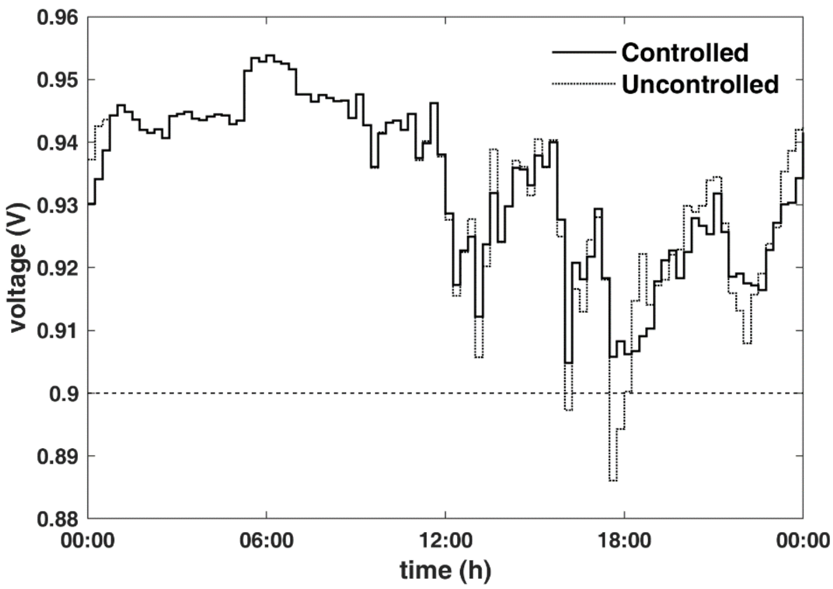

Fig. 2. Voltage variation at a connection node (192) with an EV.

To sum up, our transient simulation study confirms that I (U) control mechanism helps the distribution grid operators to meet the voltage regulations defined in the standards. In addition, the absence of communication requirement possibly makes the implementation economically more feasible. Nevertheless, it is worth to note that the EVs connected at the end of the feeders are charged at a lower rate due to the low voltages experienced. Therefore, the proposed method will be extended to incorporate the fairness among the EVs spatially distributed in the grid by setting different reference voltages for different nodes.

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Follow up Projects

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