Private, packetized plug-in electric vehicle charge management method

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Abstract

Because large-scale plug-in electric vehicle (PEV) adoption could cause local or wide-spread grid failures due to simultaneous battery replenishing, a charge management system will need to be developed to mitigate stress on the grid. While electrical companies would prefer residential charging of PEVs to be carefully monitored, consumers are wary of technologies that may infringe upon their privacy. One method that mitigates strain on the grid without compromising user privacy is called packetized charging (PC). PC is a probabilistic automaton approach that approves or denies PEV charge requests at discrete intervals. PC requires just one input: urgency of charge.

I. Introduction

With rising oil prices, higher fuel economy standards for automobile manufacturers [1], and increased environmental awareness, interest in plug-in electric vehicles (PEVs) is growing. In the U.S., where highway vehicles alone account for 55% of nationwide oil use [2], electric vehicles provide an intriguing, alternative mode of transportation. The U.S. Electric Power Research Institute (EPRI) estimates that, under a moderate penetration growth, 62% of new U.S. vehicles in 2050 will be PEVs [3]. Tangible evidence of PEV growth comes from the fact that U.S. PEV sales grew from 17,433 in 2011 to 49,962 in 2011. Through September of 2013, 53,279 PEVs had been sold in the U.S. [4].

Two-thirds of PEV charging currently occurs in a residential setting [5]. Residences typically receive Level 1 and Level 2 power, where charging a PEV via Level 1 power requires no additional

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circuit modification [6]. Residential Level 2 charging is considered in this work, because Level 2 charging is roughly twice as fast as Level 1 charging and has widespread adoption: In 2013, 90% of California's 12,000 PEV drivers used Level 2 chargers, with California drivers composing 35% of U.S. drivers [7].

In Level 2 charging, 240V at 30A, power consumption is 7.2kWh, where the typical conventional U.S. household energy expenditure is roughly 1.25 kWh per hour if averaged across the entire day [9]. Recognizing that more power is consumed at peak hours, it is still realistic to conclude that adding a PEV to a conventional residence more than doubles the electricity load during the 8 or more hours that the PEV is charging [8]. Load analyses that define present distribution systems are not built to include added PEV charging loads; as a result, large-scale PEV uptake could result in power quality degradation and grid damage on both the consumer and utility ends.

Of particular concern are neighborhood-scale, service transformers, which are aged substantially more under Level 2 charging than Level 1 charging [10]. A dynamic pricing scheme approach, leveraging smart grid communication infrastructure, may be implemented to manage the unbalanced, random, and dynamic load; however, this technology increases personal information transfer bringing increased concerns over customer privacy, consumer fraud via remote meter manipulation, and large-scale attacks on the grid [11]. Previous work that considers optimized PEV charging relies on various information from the user as illustrated in Table I.

TABLE I: CM Methods

	Desired price	**Real-time price**	**Present state of charge (SoC)**	**Daily load curve**	**PEV charge priority**	**Time over which PEV connected**	**User set charge duration**	**Node-specific power consumption**	**Node-specific charging rate**	**Node-specific charging efficiency**	**Node-specific charging strategy**
[12]	✓	✓	✓			✓					
[13]		✓	✓	✓	✓	✓	✓	✓			
[14]		✓				✓	✓	✓	✓	✓	✓
[15]					✓						

The charge management (CM) scheme considered herein – packetized charging (PC) [15] – takes just one input, PEV charge priority, to sort PEV nodes and allocate charge. Packetized charging (PC) is adapted from bandwidth sharing in communication systems, specifically Media Access Control (MAC) protocols. MAC's primary objectives are to efficiently manage channel throughput and simultaneously ensure latency is within the user's requirements. Similarly, PC aims to manage distribution feeder capacity whilst delivering ample PEV charge to users in requisite time. Just as the discrete 'data packets' sent through MAC revolutionized communications, the discrete 'charge packets' of PC could revolutionize PEV charging. In PC, vehicles make charge requests, which are granted or denied by a substation controller that assesses local conditions before making decisions. The controller divides vehicles into *n* probabilist states based upon vehicles' charge urgency and request decision history, where vehicles are moved to a higher probability after being granted the right to charge and a lower probability after being denied. A 3-state automaton, shown in Figure 1, aptly describes the PC method.

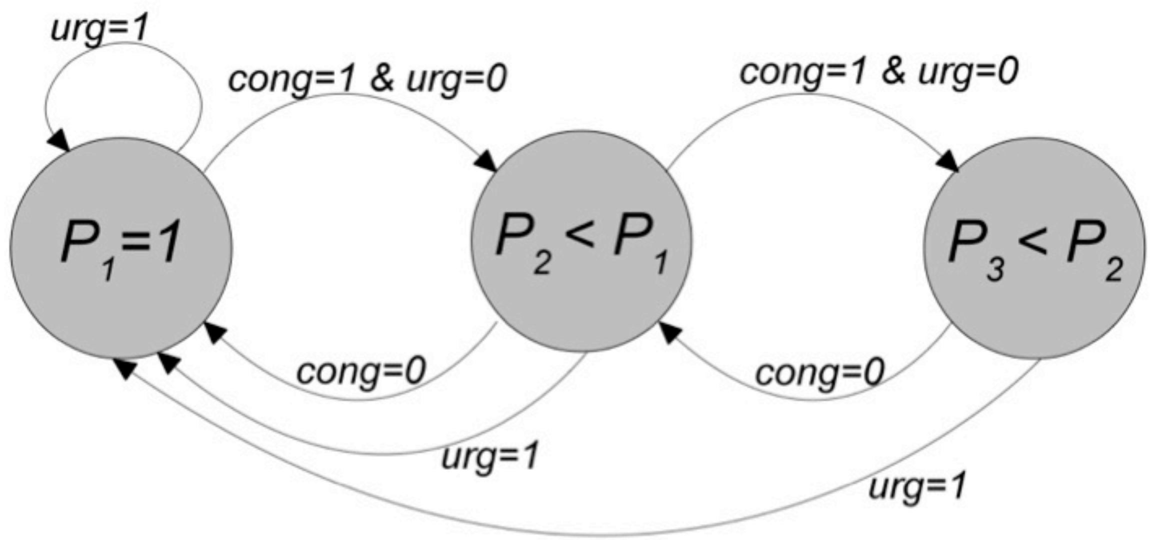

Fig. 1: A three-state (n = 3) automaton where P_2 corresponds to a lower probability of PEV charge request than P_1, and P_3 to a lower probability than P_2. In case of charge urgency (*urg=1*) the state machine will stay at P_1, but if there is no charge urgency by driver's call (*urg = 0*), and the power transformer was congested (*cong = 1*), the charge request is denied to avoid transformer overload and the PEV state machine will go to a state with lower probability. If charge urgency was set by the driver (*urg = 1*) the state machine will go to P_1 with the highest probability [15].

II. Objectives

Past simulations in PC [15] in a constrained residential distribution feeder showed that PC outperforms first come, first serve (FCFS) and is just 0.9% to 5.2% more costly than an omniscient optimal optimization method. In this work, a more accurate battery model and a specific "smart" distribution system will be used and the performance of PC under those conditions will be tested. Upon confirmation that PC outperforms FCFS, it shall be proven that PC maintains customer privacy; the current PC method will be shown to have output information that is entirely void of identifying characteristics of any specific charging location.

III. Methodology

A packetized approach to CM will be applied to a 449 smart grid distribution system, as in [13]. Simple, non-linear battery models will account for the cycling history of the battery. Models will also reflect a delay in measured charge that results from bursts of charge applied to a battery, which is inherently packetized charging [12]. The frequency of packets delivered is estimated at 1mHz, or approximately 15 minutes. Burst charging at 0.1Hz - 1Hz has been found to have no adverse effects on lithium ion batteries [16]. The assumption is made that 1mHz packetized charging will similarly have no adverse effects on the battery. A MATLAB program will accomplish probabilistic, automaton packetized charging. The program will maintain the anonymity of each PEV by removing identifying characteristics of each PEV immediately after the first automaton state. The PEVs will take on only the identity of the finite state in which they have been assigned, because the charge manager in the probabilistic approach needs only to select the inhabitant of a state, rather than any specific PEV.

IV. Data

To satisfy the objective of performance, deliverable data will be the rate of instances of successfully charged PEVs with PC versus FCFS. PEVs will be assumed to begin charging at 8:00pm, with urgent users beginning in P_1 and non-urgent users beginning in P_3 of the (Fig.1) 3-state automaton. All information shared between the controller and individual PEVs will be output to easily determine the degree of privacy existent in PC.

V. Conclusions

Conclusions will address the robustness of PC versus the optimal method of [15] at penetration levels up to 50%, which may be realistic for certain future neighborhoods having much higher penetration than the aggregate. As introduced, numerous models exist [12],[13],[14] that take a variety of inputs to provide a structured charging plan. In this work, an evaluation of the ability of private PC to compete with omniscient, optimal models will be developed. Anectodal users will represent common PEV users. Then, the primary deliverable shall be a chart that describes, for distinct, anectodal users, the exact information the user shared with PC and the charging statistics that PC delivered in return.

VI. References

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