Lottery-based Resource Allocation for Plug-in Electric Vehicle Charging*

(Extended Abstract)

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ABSTRACT

The near-future penetration of plug-in electric vehicles (PEV) is expected to be large enough to have a significant impact on the power grid. If PEVs were allowed to charge simultaneously at the maximum power rate, the distribution grid would face serious problems of stability. Therefore, mechanisms are needed to coordinate the charging processes of PEVs. In this paper, we propose an allocation policy inspired by lottery scheduling that aims at balancing fairness and selfishness, providing preferential treatment to the PEVs that have a high valuation of the electricity, while guaranteeing a non-zero share of the available power to all the PEVs to ensure fairness.

Categories and Subject Descriptors

I.2.11 [**Artificial Intelligence**]: Distributed Artificial Intelligence—*Intelligent agents, multiagent systems*

General Terms

Algorithms, Experimentation

Keywords

Lottery scheduling, resource allocation, smart grids, plug-in electric vehicles

1. INTRODUCTION

Plug-in electric vehicles (PEVs) are expected to heavily penetrate the automotive market around the world. Thus the power grid could be greatly affected by the use of PEVs. Depending on when (and also where) the PEVs are plugged in, they could cause serious reliability problems to the local grid [1], since historically it has not been designed for that kind of intensive loads.

In this paper we present an allocation policy inspired by lottery scheduling that allows multiple PEVs to charge simultaneously at different charging rate.

2. ALLOCATION POLICY

We use a model of a local distribution grid composed of a substation and several charging spots. The substation converts the voltage from medium to low and feeds the charging spots where PEVs can be plugged in.

Due to the physical limitation of the distribution grid, a substation is able to provide a certain amount P of power (in kW) to the set of charging spots $\mathcal{V}$. The task of the substation agent is therefore allocating the available power P among the plugged PEVs by setting an appropriate power supply ω_i for each charging spot so as $\sum_{i\in\mathcal{V}} \omega_i \leq P$.

The substation allocates the available power P using a policy inspired by lottery scheduling, a randomised resource allocation mechanism that has been developed for operating systems [2]. Since in our problem the resource to be granted (i.e., the available power P) is infinitely divisible, the outcome of the allocation is *not a single winner*, but the determination of a share of the disputed resource, proportional to the number of tickets, to be granted to *each participant*.

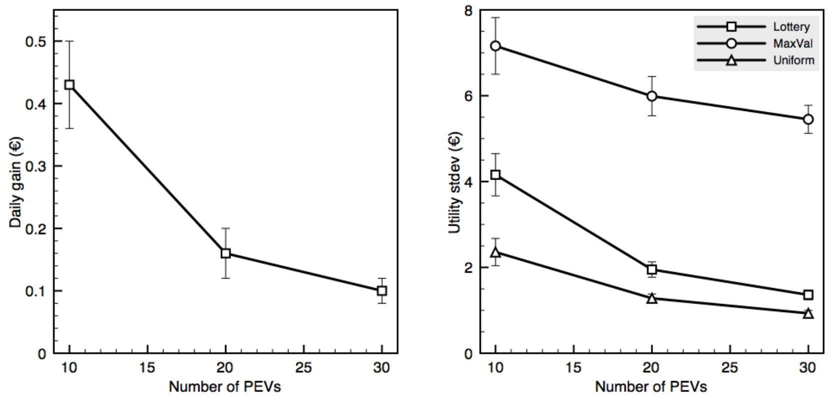
Let g be the amount of base commodity owned by each PEV, x the amount of tickets issued by a PEV, and r the exchange rate that determines the worth of one ticket in terms of the base commodity ($x = r \cdot g$). To be eligible for receiving a share ω_i of the available power P, a PEV reports the amount of tickets issued by the PEV itself. As in lottery scheduling [2], the power supply that is provided to a charging spot with a plugged PEV is proportional to the worth of the amount of tickets issued by the PEV. This worth is given by x/r. The computation of the power supply is carried out according to Eq. 1.

$$\omega_i = \frac{\frac{x_i}{r_i} \cdot \zeta_i}{\sum_{j\in\mathcal{V}} \frac{x_j}{r_j} \cdot \zeta_j} \cdot P \tag{1}$$

Although the amount of issued tickets x is set by the PEV, the exchange rate r is set by the agent that controls the substation, which is built by the distribution grid operator. By *delaying* the update of the exchange rate r towards the "true" exchange rate x/g, the PEV is given the possibility of reporting an *inflated* amount of tickets. In this way, a PEV

*Research supported by the project "AT" (CONSOLIDER CSD2007-0022, INGENIO 2010) and "OVAMAH" (TIN2009-13839-C03-02)

Appears in: *Proceedings of the 11th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2012)*, Conitzer, Winikoff, Padgham, and van der Hoek (eds.), 4-8 June 2012, Valencia, Spain.



(a) Daily gain (b) Inequality measure

Figure 1: Experimental results

may try to increase its share ω_i by inflating the worth of its tickets so as $x/r > g$. However, assuming that the PEVs behave rationally, all of them would report an inflated amount of tickets. In this case the outcome of the allocation policy would be that none of them would actually be able to increase its power supply. This undesired outcome is avoided if we put a limit to the overall inflation. When more than a fixed percentage of PEVs report an inflated amount of tickets, the power supply of the inflationary agents is reduced by the penalisation term ζ.

3. EXPERIMENTAL EVALUATION

The main objective of the evaluation is assessing the difference, in terms of average utility of PEVs, between our allocation policy (`Lottery`) and a uniform policy that equally distributes the available power P among the PEVs (`Uniform`). We refer to this difference with the term *daily gain*, expressed in €. A PEV is assumed to have an internal combustion engine that can supply driving force when the battery is depleted. The PEV's utility function is defined according to Eq. 2, where p^c is the price of fuel (in €/litre), γ^c is the internal combustion engine efficiency (in km/litre), and γ^e is the electric efficiency (in km/kWh).

$$u(b) = \frac{p^c}{\gamma^c} d - \frac{p^c}{\gamma^c}(d - b\gamma^e) = \frac{p^c}{\gamma^c}\gamma^e b \tag{2}$$

To assess how fair is our allocation policy, we further consider the outcome of another (theoretical) allocation policy that assigns all the available power P to the PEV with the highest valuation of one unit of electricity (`MaxVal`). The outcome of this policy is the same as that of an incentive-compatible auction that assigns the disputed resource to the PEV that submitted the highest bid (i.e., the agent with the highest valuation).

Fig. 1(a) shows the daily gain in a small neighbourhood, with 10 to 30 plugged PEVs. A PEV owner may gain from 10 to 40 cents of € per day, depending on the number of PEVs that compete for the available power P. In a year, this gain can account for more than 140 €. Due to the fact that different PEVs have different valuations of one unit of electricity, a uniform allocation does not reward those agents that value electricity the most. Our allocation policy instead enables the agents with higher valuations to increase their share of the available power P.

Even though the allocation policy meets the selfishness of the PEV owners, it also enforces fairness. To assess the inequality of the evaluated policies we compute the standard deviation of the utility that the PEVs obtain at the end of charging. Fig. 1(b) shows the inequality measure of the three allocation mechanisms. As expected, `Uniform` is the fairest policy that ensures the allocations with the smallest standard deviation. `MaxVal` is the most unfair policy, since the available power P is always allocated to the PEV with the highest valuation, at the expense of the PEVs that, albeit with a lower valuation, still have energy needs. `Lottery` falls in between and tends to approach `Uniform` when the number of PEVs in the system grows.

4. CONCLUSIONS

In this paper we put forward an allocation policy inspired by lottery scheduling to automatically coordinate the simultaneous charging of several PEVs. We demonstrated how our allocation policy is capable of balancing fairness and selfishness: it provides preferential treatment to those PEVs that value the electricity the most (they can report an inflated amount of lottery tickets so as to increase their share of the available power P), while guaranteeing a non-zero share of P to all the PEVs. The experimental evaluation showed that our allocation policy always ensures a utility gain compared to a straightforward uniform allocation, with gains that can reach up to 140 € per year in some scenarios. Furthermore, it reduces inequality with respect to a hypothetical allocation policy that fully assigns the disputed resource to the PEV with the highest valuation.

5. REFERENCES

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