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# Electric vehicle charging under power and balance constraints as dynamic scheduling ☆,☆☆

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ABSTRACT

Scheduling appropriately the charging times for a set of electric vehicles may lead to energy savings but at the same time it may be a hard problem. In this paper, we consider a problem of this family, which is motivated by a private community park where each parking space belongs to a particular user and has a charging point connected to one line of a three-phase electric feeder. The number of vehicles in each line and the difference in the vehicles in every pair of lines charging at the same time are limited. We model this problem in the framework of Dynamic Constraint Satisfaction Problems (DCSP) with optimization, and so it is defined by a sequence of CSPs over time. We propose a solution method that decomposes each CSP into three instances of a one machine sequencing problem with variable capacity. This method was evaluated by simulation on a set of instances defined from different scenarios of vehicle arrivals, departures and energy requirements. The results of the experimental study show clearly that the proposed algorithm is efficient and that it outperforms a classic dispatching rule.



## 1. Introduction

It is well known that the use of Electric Vehicles (EVs) may have a positive impact on the economy and the environment due to promoting the use of alternative sources of energy and relieving the dependency of petrol. Furthermore, the energy stored in EVs may be utilized as an ancillary service resource (Kang, Duncan, & Mavris, 2013) for regulating frequency and voltage profiles as well as to compensate fluctuations in renewable energy generation (Dallinger, 2014).

At the same time, the emerging fleet of EVs introduces some inconveniences such as the additional load on the power system or the time required to charge the batteries. As pointed in (EDSO, 2012), one of the challenges in EVs' technology is developing smart systems for charging control to avoid increasing peak demand. In fact, a number of charging control systems have already been proposed (Gan, Topcu, & Low, 2007; Wu, Aliprantis, & Ying, 2012; Ma, Callaway, & Hiskens, 2013) that, in some cases, try to fill the overnight valley in order to reduce daily cycling and operational cost of power plants.

In this paper we consider a real life scheduling problem motivated by the charging station described in (Sedano et al., 2013). This system was designed to be installed in a community park under simplicity and economy criteria. Each stall belongs to a particular user and has a charging point connected to one of the lines of a three-phase electric feeder. A centralized control establishes the available power in each charging point over time. There are power constraints limiting the number of vehicles that can be charging at the same time on the same line and balance constraints that limit the difference in the number of vehicles charging in every pair of lines. Due to these technological constraints and to the dynamic nature of the problem derived from the fact that the arrival of the vehicles is not known in advance, it is not easy to organize the charging periods of the vehicles over time in such a way that all customers are satisfied and the system makes the best use of the contracted power at the same time. Therefore, a scheduling algorithm is a key element of the control system for the charging station performance.

The main goal of this paper is the design and analysis of an efficient and effective algorithm for the electric vehicle scheduling problem in a charging station with the particular characteristics mentioned above. To this end, we model the problem in the framework of Dynamic Constraint Satisfaction Problems (DCSP) with optimization. Therefore, it requires solving a number of static CSPs over time. We propose a solution method that decomposes each CSP into a number of instances of a one machine scheduling

☆ Some preliminary results of this research work has been discussed in (Hernández-Arauzo, Puente, González, Varela, & Sedano, 2013).
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problem with variable machine capacity, which as far as we known is the first time it appears in the literature. The scheduling algorithm is evaluated by simulation and compared with a classic Latest Starting Time (LST) rule.

The rest of the paper is organized as follows. In the next section we summarize the characteristics of the charging station that are relevant from the point of view of the scheduling algorithm. Then, in Section 3, we review some of the recent literature related to EVs charging scheduling. After that, in Section 4, we define the problem as a DCSP. Section 5 follows with a detailed description of the proposed solving procedure. In Section 6, we report the results of the experimental study and finally, in Section 7, we give some conclusions and ideas for future research.

## 2. Description of the structure and the operation of the charging station

The main characteristics of the electrical structure and the operation mode of the charging station are detailed in (Sedano et al., 2013). Fig. 1 shows the schema of the distribution grid, which is designed to be installed in a private community park where each user has his own space. The design criteria of the control system were based on simplicity, economy and maintenance easiness. The grid is fed by a three-phase source of electric power with a voltage between phases of 400 V. Each charging point is connected to one single-phase and supplies energy at 230 V and 2.3 kW (Sedano et al., 2013). So, for a given contracted power, there can be a maximum number of vehicles charging in a line at the same time. Also, the consumption in the three lines should not be too different at any time. Otherwise, the net is imbalanced and there is current in the neutral point. This causes higher losses than those of a balanced system and lowers the energy transmission efficiency. Moreover, the Spanish regulations (BOE, 2013) do not allow the installation of devices that produce large imbalances without the consentient of the supplier company, which can penalize the customer for it.

The station is controlled by a distributed system composed of a master and a number of slaves. Each slave controls two consecutive charging points in the same line. The master accesses the database where the vehicles' data and the charging schedule are stored. It gathers information about the demanding vehicles from the slaves, and sends connection/disconnection orders to them. So the slaves are responsible for activating and deactivating charging points as well as recording asynchronous events such as a new vehicle arriving to the system. When entering in the station, the user parks the vehicle in his own space (as he cannot use the space of another user) and connects the vehicle to the charging point. Then, he has to provide the charging time and the time he will take the vehicle away (due date). From these data, the control system schedules the charging times of the vehicles. The objective is in principle that all users can be served by their due dates. However this is not always possible and in that case what we try to do is minimize the overall time beyond the due dates for all users; i.e., the total tardiness. Of course, other objective functions could be considered instead as, for example, the maximum tardiness in order to not penalize a particular user in excess with respect to the remaining ones.

In this paper we consider a simplified model of the operating mode of the charging station that makes the following assumptions: the user never takes the vehicle away before the due date and the battery does not get completely charged before the charging time provided by the user. These are in fact unrealistic assumptions, however the model may be adapted by introducing new asynchronous events if they do not hold.

Each time a new vehicle requires charging, a new schedule should be build. In principle, the system could try to accommodate the new vehicle without changing the schedule for the remaining vehicles in the system. However, this may not be the best option. So, in order to obtain a new feasible schedule as good as possible, all vehicles in the system that have not yet started to charge may be rescheduled, and a new schedule is build with these vehicles together with the new ones. In this process, the available resources determined by the contracted power, the imbalance constraints and the vehicles that are currently charging, must be taken into account to build the new schedule.

Moreover, in order to avoid the system to collapse if, for example, many vehicles arrive in a very short period of time, new schedules are built at regular time intervals. In order to do that, after every time interval $\Delta T$ (typically 120 s) or larger, a supervisor program running on the server checks for the events produced in the last interval. If at least one event was produced then the scheduler

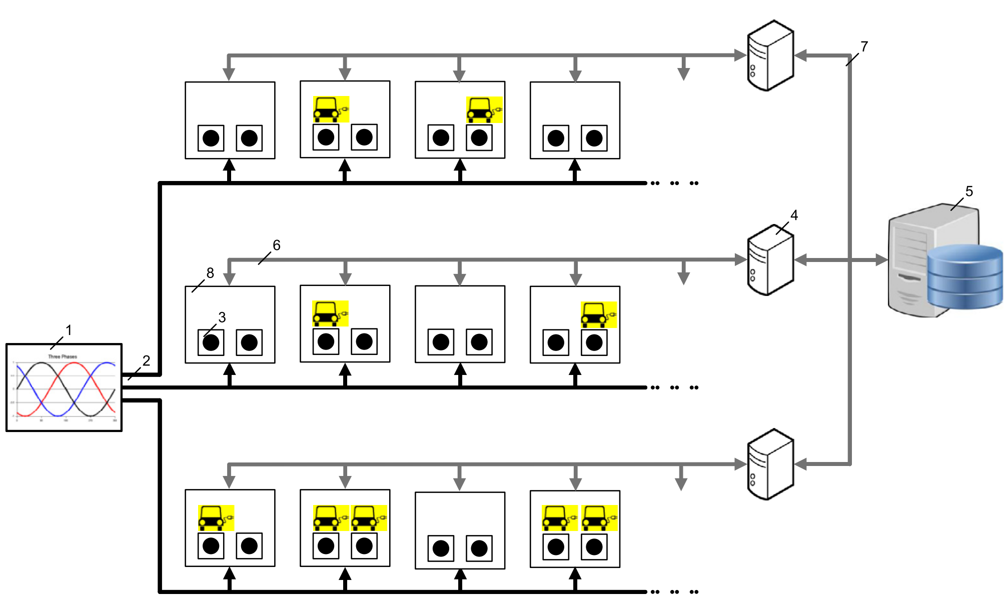


**Fig. 1.** General structure of the distribution net of charging stations. It is formed by different parts such as: (1) power source, (2) three-phase electric power, (3) charging points, (4) masters, (5) server with database, (6) communication RS 485, (7) communication TCP/IP, and (8) slaves.