# A Tabu Search Algorithm for Maximizing Delivered Energy in Electrical Charging Stations

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## 1 Introduction

In this study, we address the scheduling problem associated with charging electric vehicles at a public charging station with the objective of maximizing energy delivery. The configuration considered aligns with that presented in [2]. The charging station is equipped with m points (CPs), each denoted as CP i (where i = 1, ..., m), capable of being toggled on and off during charging, featuring a specific output capacity of  $w_i$  (kW). The maximum power supply for the station is restricted to  $w_G$  (kW), rendering it infeasible to operate all chargers simultaneously. The study focuses on a one-day timeframe, divided into time slots of length  $\tau$ .

Charging demands, represented by  $J = \{J_1, \ldots, J_n\}$ , are characterized by arrival time  $r_j$ , departure time  $d_j$ , initial state-of-charge  $e_j^0$ , desired state-of-charge at departure  $e_j^f$ , and vehicle battery capacity  $B_j$ . Each demand corresponds to a vehicle, and each vehicle occupies a charger for its entire charging duration. Charging commences at a specific time on one charger at  $s_j$   $(r_j \leq s_j < d_j)$ , without interruption.

Our goal is to find a schedule for these demands to achieve the desired charge levels, accounting for the constraints imposed by the limited number of chargers and the station's power capacity. The objective is to minimize the total difference between the desired and final charge levels.

# 2 The proposed method

Our methodology employs a bi-level optimization strategy. In the initial phase, we utilize the tabu search algorithm to ascertain the assignment of demands to chargers. Subsequently, in the second phase, we focus on determining the power allocation for each accepted demand within each time slot during the plugging time.

**Assignment:** A solution is represented by matrix M and vector S. Matrix M (with m + 1 rows) denotes chargers and rejected demands, where each row i (i = 1, ..., m) contains sorted demands  $J^i \subseteq J$  assigned to charger i. Vector S (size n) signifies the plugging time for accepted demands. For consecutive demands j and j' on charger i with due dates  $d_j$  and  $d_{j'}$   $(d_j < d_{j'})$ , plugging time  $s_{j'} = \max(d_j, r_{j'})$  optimizes charger utilization by ensuring timely plugging.

**Power allocation:** After assigning demands, the next step is determining electric power distribution for each charger and time slot.

sc	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
J	47	49	58	65	50	57	52	67	51	53	39	39	36	32	38
TS	0.55	0.51	0.48	0.68	0.54	0.54	0.42	0.7	0.41	0.78	0.34	0.4	0.34	0.21	0.29
SA	1.71	2.24	1.18	2.37	1.63	2.64	1.3	3.65	1.25	2.76	0.78	0.9	0.63	0.38	0.58

TAB. 1: Comparison of the results of the heuristics and meta-heuristics with m = 20.

We use an MILP model with continuous parameters  $e_{jt}$  for each demand j and time slot t. Here,  $e_{jt}$  is  $w_i$  if demand j is assigned to charger i during  $s_j \leq t < d_j$ , and 0 otherwise. The set V identifies time slots where energy demand surpasses station capacity  $(V = t | \sum_{j=1}^{n} e_{jt} > W_G)$ . Binary variables  $y_{jt}$  indicate whether demand j charges at time slot t.

$$\min \sum_{j=1}^{n} (e_j^d - e_j^0) - \sum_{j \in S} \frac{\tau}{B_j} \sum_{t \in [s_j, d_j)} e_{jt} y_{jt}$$
(1)

subject to

$$\sum_{j \in S} \frac{\tau}{B_j} \sum_{\substack{t \in [s_j, d_j) \\ j \in S \\ t \in [s_j, d_j)}} e_{jt} y_{jt} \leq e_j^d - e_j^0 \quad \forall j \in S$$
(2)  
$$\sum_{\substack{j \in S \\ t \in [s_j, d_j) \\ y_{jt}}} e_{jt} y_{jt} \leq W_G \quad \forall t \in V$$
(3)  
$$\forall j \in S, t \in T$$
(4)

Objective function (1) measures the difference between requested and obtained state-ofcharge levels for accepted demands. Constraints (2) prevent exceeding requested energy levels for each accepted demand, and constraints (3) cap the total output power during peak time slots at the charging station limit.

#### 2.1 Tabu search algorithm with LP models

The Tabu Search (TS) algorithm, introduced by [1], mitigates local optima by allowing nonimproving moves. TS starts with a feasible initial solution, iteratively refining it by exploring a solution set around the current one. The neighborhood consists of feasible solutions achievable through simple moves. At each iteration, neighboring solutions are generated, evaluated based on the objective function, and the current solution is moved to the best neighbor, even if it worsens the objective value. The move is added to the tabu list to prevent revisits and cycling. The algorithm stops on meeting a predefined criterion, returning the best solution found.

The move involves a tuple (i, j), with i as the machine index and j as the selected demand index. The algorithm shifts demand j from its current charger i to another charger, specifically charger h within solution M.

We present results for 20 chargers and a demand range of 32 to 67 in Tab. 2.1, comparing our method with the simulated annealing approach from [2]. The superiority of our method is evident in the obtained results.

### References

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