Design & Analysis of Algorithms

CS-251

Project Report

Electric Vehicle Charging Scheduling Problem

Team Members

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Deadline: 16th May, 2022

Introduction to the Project

Background Information

The market share of Electric Vehicles has grown significantly over the years. The growing number of Electric Vehicles along with the unprecedented advances in battery capacity and technology have resulted in an overwhelming increase in the total energy demand of EVs. The large charging demand has made the EV charging scheduling problem very challenging. An apparent challenge is that even whilst taking advantage of the deferrable property of charging demands and proper scheduling, the aggregate demand might be beyond the tolerable charging capacity of the station, considering the physical constraints of charging devices and transformers. Furthermore, in practice, EVs arrive at charging stations in online fashion and the charging station has thus not been notified in advance about the arrival and demand of these EVs. This makes the charging scheduling even more challenging.

Purpose

The purpose of this project is to provide a scheduling algorithm for charging of EVs that deals with

- charging of the vehicles arriving in online fashion
- provision of on arrival commitment
- consideration of the power capacity constraint of charging stations

Scope

The project will provide a detailed analysis of an improved version of the initial charging scheduling algorithm along with its constraints. The improved algorithm will deal with some of the shortcomings that persist in the initial algorithm and a complete theoretical analysis comparing the performance of both algorithms will be performed.

Objective

The objective of this project is to analyze the charging algorithm presented in the research paper and to provide an improved version of the algorithm that will be more practical to the real-life EV charging scheduling problem.

Contributions

Initial Algorithm

Algorithm 1: SCOMMIT: $\forall t \in \{1, \ldots, T\}$

Input: EVs to arrive on the fly
Output: A feasible charging scheduling

$\mathcal{N}^t \leftarrow \{i \in \mathcal{N} : t \in \mathcal{T}_i\}$
$r_i^t \leftarrow D_i - \sum_{u=a_i}^{t} y_i^u, \forall i \in \mathcal{N}^t$
$\mathcal{W}^t \leftarrow \{i \in \mathcal{N}^t : y_i^t = 0, r_i^t > 0\}$
if *there are new arrivals* **then**
    $\mathcal{L} \leftarrow$ Sorted list of new arrived EVs in a non-increasing order of their unit value (i.e., $\frac{v_i}{D_i}$)
    foreach *EV* $i \in \mathcal{L}$ **do**
        $\gamma_i \leftarrow$ SETGAMMA(i)
        if $\gamma_i > 0$ **then**
            PRESCHEDULEEV(i)
        else
            $\mathcal{W}^t \leftarrow \mathcal{W}^t \cup \{i\}$
    if $\mathcal{W}^t \neq \emptyset$ **then**
        RESCHEDULEEVS($\mathcal{N}^t$)
else
    if $t > 1$ **then**
        foreach *EV* $i \in \mathcal{N}^t$ **do**
            if y_i^t *is not set yet (by* PRESCHEDULEEV*)* **then**
                $y_i^t \leftarrow \min\{y_i^{t-1}, r_i^t\}$
                Update r_i^t

Notation	Description
a_i	Arrival time of EV i
d_i	Departure time of EV i
D_i	Demand of EV i
v_i	Valuation of EV i for receiving its demand D_i
k_i	Maximum charging rate of EV i in kW
r_i^t	Residual demand of EV i at t i.e., $D_i - \sum_{t'=a_i}^{t} y_i^{t'}$
$\mathcal{N}$	Set of all EVs with $\lvert\mathcal{N}\rvert = n$, indexed by i
$\mathcal{N}^t$	Set of available EVs at t
$\mathcal{C}^t$	Set of active EVs at t with $y_i^t > 0$
$\mathcal{W}^t$	Set of active EVs at t with $y_i^t = 0, r_i^t > 0$
T	Number of time slots, indexed by t
$\mathcal{T}$	$\{1, 2, \ldots, T\}$
$\mathcal{T}_i$	$\{a_i, a_i + 1, \ldots, d_i\}$
P	Power capacity constraint (in kWh) in charging station
C	Slot capacity constraint (i.e., number of charging slots)
y_i^t	**opt. variable**, The amount that EV i is charged at t
γ_i	**opt. variable**, Commitment given to EV i on its arrival
x_i^t	**opt. variable**, $x_i^t = 1$, if $y_i^t > 0$ and 0, otherwise

Algorithm 3: PRESCHEDULEEV

Input: EV i to be scheduled for charging
Output: Charging plan for EV i

$R_i \leftarrow \gamma_i D_i$
$t \leftarrow a_i$
while $R_i > 0$ **do**
    if $\sum_i x_i^t < C$ **then**
        $r \leftarrow \min\{k_i, R_i, P - \sum_{j \in \mathcal{N}^t} y_j^t\}$
        $y_i^t \leftarrow r$
        $R_i \leftarrow R_i - r$
        $t \leftarrow t + 1$

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Algorithm 4: RESCHEDULEEVS

Input: $\mathcal{N}^t$
Output: A new charging decision for time slot t

Sort EVs in $\mathcal{W}^t$ in a non-increasing order of their unit value
while $(\sum_{j \in \mathcal{N}^t} y_j^t < P) \wedge (\mathcal{W}^t \neq \emptyset)$ **do**
    $i \leftarrow$ the next EV in ordered set $\mathcal{W}^t$
    if $(\exists j \in \mathcal{C}^t : v_i/D_i > v_j/D_j) \vee \Big[(\sum_{j \in \mathcal{N}^t} y_j^t < P) \wedge (\sum_i x_i^t < C)\Big]$ **then**
        Pause charging of EVs with lower priority (if necessary) without violating charging commitments
        $y_i^t \leftarrow \min\{k_i, r_i^t, P - \sum_{j \in \mathcal{N}^t} y_j^t\}$

Pseudocodes:

Algorithm 1: SCOMMIT: ∀t ∈ {1,..., T }
Input: EVs to arrive on the fly
Output: A feasible charging scheduling
The algorithm creates the set of

- all EVs available at time t
- residual demand of each EV at time t
- active EVs with zero commitment and non-zero residual demand

If there are new arrivals at time t, then for each new EV (in decreasing order of unit value), a commitment value is set using the SETGAMMA function. If a non-zero commitment is assigned then a charging plan using the PRESCHEDULE function is assigned to that EV. In case of zero commitment, the EV is added to the list of EVs with zero commitment and non-zero residual demand.

And if the list of EVs with zero commitment is non-empty, then we try to assign a new charging decision for those EVs at time t using RESCHEDULE.

However, if at some time after the first time slot no new EVs have arrived for t, then for each EV available whose commitment value hasn't been set for that time t, a new commitment value is assigned equal to the lesser value between commitment value for previous time slot and residual demand at t, and the residual demand is updated.

Algorithm 2: SetGamma

Input: Profile of EV i, parameters $\Delta \in \mathbb{Z}^+$, and $\alpha \in [0, 1]$
Output: γ_i

$\gamma_i \leftarrow 0, s \leftarrow 0$
for *each t in* $\mathcal{T}_i$ **do**
  if $\sum_i x_i^t < C$ **then**
    $s \leftarrow s + \min\{k_i, P - \sum_{j \in \mathcal{N}^t} y_j^t\}$
if $\sum_{t \in \mathcal{T}_i} \sum_j y_j^t \leq \alpha(d_i - a_i + 1)P$ **then**
  $\gamma_i \leftarrow \min\{1, s/D_i\}$
else
  $\mathcal{A}_j \leftarrow \{j \in \mathcal{N} : \mathcal{T}_j \cap [a_i - \Delta, a_i] \neq \emptyset \text{ and } \gamma_j = 1\}$
  $\text{th} \leftarrow \frac{\sum_{j \in \mathcal{A}_j} v_j / D_j}{|\mathcal{A}_j|}$
  if $\frac{v_i}{D_i} > \text{th}$ **then**
    $\gamma_i \leftarrow \min\{1, s/D_i\}$

Algorithm 2: SETGAMMA
Input: Profile of EV i, parameters $\in Z^+$, and $\alpha \in [0,1]$
Output: γ_i

The algorithm takes the profile of EV as input and outputs a commitment ratio ∈ [0, 1]. In the first part, it checks how much total energy the charging station can commit in the availability window of the EV. Once done, the algorithm checks **1)** if within the availability window of the EV, the total energy committed with other EVs is at most α times the total energy that the charging station could provide in the availability window. α is a parameter that stays the same for each run of the algorithm and decides how "conservative" the algorithm will be, in making a commitment. Note that here 'conservativity of algorithm' means the holding back from making a charging commitment in hope of making a commitment with future EVs offering more per unit value. If condition **1** fails, then the algorithm checks if the *average per unit value* of the EVs (whose availability window overlaps with the availability window of the current EV) is less than the per unit value of the current EV. If this condition is satisfied, a minimum of {1, ratio of energy charging station can provide and the total demand} is committed with the EV.

Algorithm 3: PRESCHEDULEEV

Input: EV *i* to be scheduled for charging

Output: Charging plan for EV *i*

The algorithm runs while remaining commitment for the EV is non-zero. If a charging slot is available at t, a suitable charging rate for the EV is assigned for t and is set as the new commitment value for the EV for t. The remaining commitment and time gets updated.

Algorithm 4: RESCHEDULEEVS

Input: W^t

Output: New charging decision for time slot *t*

Set of EVs active at t with zero commitment is sorted in decreasing order of unit value. While the grid has energy to charge more EVs and the set W^t is non-empty, we take the next EV from the set.

1) If a charging slot is available, then despite whether the current EV does or does not have enough commitment value, a minimum suitable commitment value will be assigned to the EV for an available charging slot. **2)** If a charging slot is NOT available but the current EV has higher unit value than some already committed EV. **3)** If neither a charging slot is available nor does the current EV have a higher commitment value than an already committed EV, nothing will happen

Improvements

Definition of Pausing EV - Algorithm 5

Working principle is "**Pause charging of EVs with lower priority (if necessary) without violating charging commitments"**

New variable part of EV profile: $\mathbf{sD_i = s/D_i}$

Function PauseEVfor(EV_j, t_x):

For each EV_i in $\left\{EV_i \in C^t: \frac{v_i}{D_i} < \frac{v_j}{D_j} \wedge sD_i > 1\right\}$:

rc = $\sum_{t=t_x}^{d} y_i^t$

s = 0

For each t in $\{t_x + 1, .., d\}$:

If $|C^t| - x_i^t < C$:

$s \leftarrow s + min\{k_i, P - \sum_{\substack{q \in C^t \\ q \neq i}} y_q^t\}$

EndIf

EndFor

$sD_i \leftarrow \frac{s}{rc}$

If s>=rc:

r = rc;

t = $t_x + 1$

While $r > 0$:

If $|C^t| - x_i^t < C$:

$y_i^t = min\{r, k_i, P - \sum_{\substack{q \in C^t \\ q \neq i}} y_q^t\}$

$r \leftarrow r - y_i^t$

EndIf

$t \leftarrow t + 1$

EndWhile

$\boldsymbol{Return\ True}$

EndIf

EndFor

$\boldsymbol{Return\ False}$

EndFunction

Error Fixes

Two errors identified:

- **"t"** should be incremented out of if structure in PreSchedule
  Otherwise it would go in infinite loop, if a slot is not free

- If an EV was rescheduled the case of no new EV arrival in next time slot lead to inconsistent state
  More EVs would be charging then total chargers available, which is not possible.
    - So, in that case allocation condition should be added:
        - If charging spot available

Analysis and Results

Time Complexity Analysis

Algorithm	Big O complexity
1	$n ((d-a)(\|Nt\|))^2$
2	$(d-a)(\|Nt\|)$
3	$(d-a)(\|Nt\|)$
4	$(d-a)\|Ct\|^2\|Wt\|\|Nt\|$
5	$(d-a)\|Ct\|^2$

Detail Analysis

- For level 2 charger up-to 44 miles/hr (70 km/hr) (7.8 - 17 kw)
    - It is recommended by Tesla to be used when one have couples of hours to spare
    - Such locations like parking for schools and university or offices

- Time slicing of one hour
    - A car could have to wait up-to an hour for getting first response
        - This not a problem if vehicle movement is handled by service provider

    - If a car could charge in 1 hr 10 min
        - It would be allotted 2 hr
        - In the last hour it would be charged slowly so that it takes 2 hr

- Do not consider max charging speed variation
    - Just consider constant max charging speed, ki

- **Limit on overall parking space not mentioned**

- Considers cars to be moved as per schedule
    - As it pause cars, may Start charging after several hours of arrival and reschedule cars charging
    - Which might require
        - autonomous driving enabled and wireless charging
        - Human intervention to move vehicles

- Pricing Scheme: the willingness of a user to pay
    - While current techniques are
        - Subscription
        - Electricity consumption
        - Electricity consumption & charging time

- **Expecting user is aware of or is provided info of avg unit value**
    - So that it can make decision on offer based on requirement which might be:
        - Charge as much as possible at x price by this time.
        - I want to charge my car by y amount in as much less money possible
            - ASAP (not supported as it may require rescheduling pre scheduled cars) - Boundary case normally people would visit level 3 chargers (300km/hr) for this purpose
            - By z time

Other Loopholes

- In Part-IV: Line 14 onward in sCommit - The ELSE block

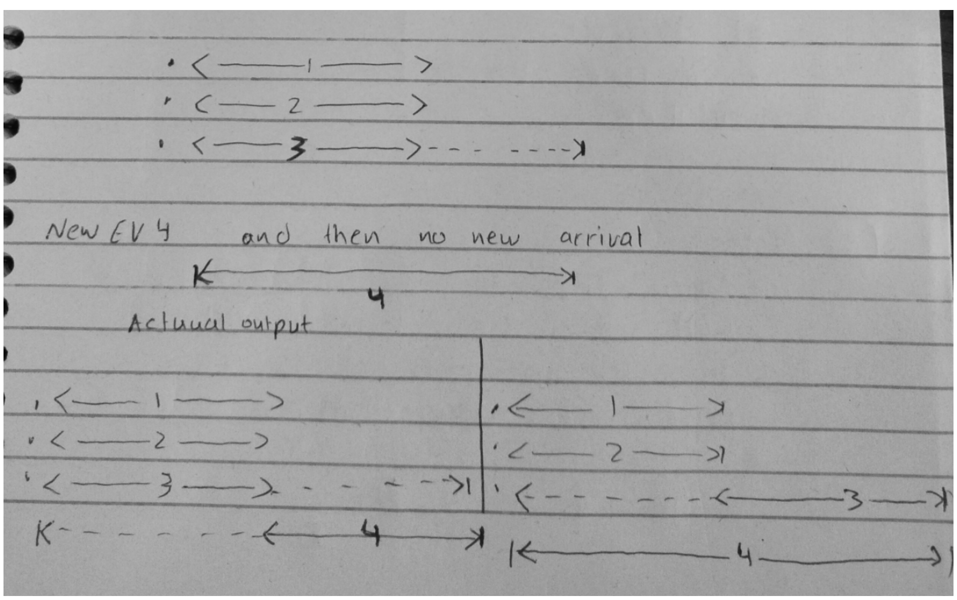
  Resources are not reallocated if an EV leaves the charging spot

  Example:

  Note: commitment with car x is 0 and $y_i^t < k_i$

  If car x is rescheduled at time t,
  At time t+1 no new car comes but a car which was charging at time t leaves.
  Which means we have free energy to be reallocated.

- Loophole In Reschedule



Conclusion

Changes to the original requirements of the project

Due to the limitation of time for this complex algorithm along with the errors and missing definitions, the following requirements had to be changed:

1. Provide definition for the pause EV functionality.
2. Fix the errors
3. Identify and document the loopholes and inefficiencies

Keeping in view the actual goal of providing a better algorithm, this project is the first stepping stone. Providing detailed analysis along highlighting special cases.

Future work that could have been done to improve the project.

The scheduling algorithm will define the interaction of EVs with a charging station. Thus, a basic research from a consumer perspective will be enough, which would for sure improve applicability of future improved algorithms.

References

Research Paper : Online EV Charging Scheduling With On-Arrival Commitment | IEEE Journals & Magazine | IEEE Xplore

Our Detailed Work : GitHub - Curious-x/Electric-Vehicle-Scheduling-Algorithm

Other references: Charging Your Tesla | Tesla