The Journal of Open Source Software

ChaProEV: Generating Charging Profiles for Electric Vehicles that support optimisation and simulation models

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DOI: 10.xxxxxx/draft

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Editor: Open Journals

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Submitted: 01 January 1970
Published: unpublished

Summary

ChaProEV is

Statement of need

Battery-electric vehicles (BEVs) as the fleets of EVS are poised to grow sharply in the future and have a strong impact on the electric grid (Smit et al., 2022; Wilde et al., 2022), and on energy systemns in general.

It is therefore important that models that seek the optimisation of energy systems or simualte them properly take BEVs into acocunt. Some models (Luxembourg et al., 2024; Stralen et al., 2021) only include fixed charging reference profiles. These profiles can be fixed in two ways: They do not take into account the dynamics of the energy system and teh grid at each time step and/or they do not integrate the specifics of the case studied by running the optimisation or simulation model.

Dynamic fit at each time: ….

Situation specifics: ….

ChaProEv was developped to improve these two elements (Özdemir et al., 2020; Sijm et al., 2022)

substequently is (Helistö et al., 2024; LNEG et al., 2020) (VTT et al., 2023) (Helistö et al., 2024) (LNEG et al., 2020) (Ihlemann et al., 2022) (Kiviluoma et al., 2022) (I. Sanchez Jimenez et al., 2024) (Johanndeiter et al., 2024) –>

energy system optimization models [Özdemir et al. (2020);Sijm et al. (2022);Stralen et al. (2021);SpineOpt;Tejada-Arango et al. (2023);Kiviluoma et al. (2022)], and simulation models (I. Sanchez Jimenez et al., 2024; Kiviluoma et al., 2022; Subramanian et al., 2020, 2021).

ChaProEV has also been used in European-level (Helistö et al., 2024; LNEG et al., 2020; VTT et al., 2023) and regional-level (Smit et al., 2022; Voulis et al., 2021; Wilde et al., 2022) projects.

ChaProEV has also integrated well into existing grid models, enabling these models to include up-to-date and customisable charging profiles of EVS (Helistö et al., 2024; I. Sanchez Jimenez et al., 2024; Ingrid Sanchez Jimenez et al., 2025; Johanndeiter et al., 2024; Kiviluoma et al., 2022; LNEG et al., 2020; Subramanian et al., 2020, 2021; Voulis et al., 2021), as well as new and custom types of constraints for optimisation models (I. Sanchez Jimenez et al., 2024;

Kiviluoma et al., 2022; Subramanian et al., 2020, 2021; VTT et al., 2023), which helps use the flexibility EVs provide to the system with G2V and V2G.

plenned/possible (Brown et al., 2018; Luxembourg et al., 2024; Stralen et al., 2021; Tejada-Arango et al., 2023)

- Profiles are good and useful, but optimisation modes might also need soem underlying parameters to do optimisation computations as well
- Provide optimisation models with the boundary conditions they need
- ChaProEV povides the necessary parameters (as explemplified in COMPETES, Mopo/Ines, etc.) in a clear and accessible way, with the also allowing a clear way to modify them without touching code (Sijm et al., 2022)

tailored to supply optimisation models (list, but also actual implementations) throug the model below by explicitely supplying the necessary parameters EV parameters for optimisation models and providing an option to change some story parameters creating new scenarios

Conceptual innovations: Supporting optimisation and simualtion models

ChaProEV provides parameters for the model below

Basic elements

A commonly used aggregated EV formulation is (Morales-España et al., 2022):

$$e_t = e_{t-1} + \eta^{\mathrm{G2V}} p_t^{\mathrm{G2V}} \Delta - \frac{p_t^{\mathrm{V2G}}}{\eta^{\mathrm{V2G}}} \Delta - E_t^{\mathrm{drive}} \Delta N \alpha \quad \forall t \tag{1}$$

$$\underline{E} N_t^{\mathrm{plugged}} N \alpha \leq e_t \leq \bar{E} N_t^{\mathrm{plugged}} N \alpha \qquad \forall t \tag{2}$$

$$0 \leq p_t^{\mathrm{G2V}} \leq \bar{P}_t^{\mathrm{G2V}} N_t^{\mathrm{plugged}} N \alpha \qquad \forall t \tag{3}$$

$$0 \leq p_t^{\mathrm{V2G}} \leq \bar{P}_t^{\mathrm{V2G}} N_t^{\mathrm{plugged}} N \alpha \qquad \forall t \tag{4}$$

where t is the time index and parameter Δ (h) is the duration of the time step. Variable e_t (kWh) tracks the total state of charge of the plugged EVs to the grid. Variables $p_t^{\mathrm{G2V}}/p_t^{\mathrm{V2G}}$ (kW) are the power consumed/provided by the EVs from/to the grid. Parameters $\eta^{\mathrm{G2V}}/\eta^{\mathrm{V2G}}$ (p.u.) are the charging/discharging efficiencies; $\underline{E}/\bar{E}$ (kWh) are the minimum/maximum storage capacity per vehicle; N is the total number of EVs; and α (p.u.) is the share of controllable EVs providing demand response to the system.

Equation 1-Equation 4 model the demand response provided by controllable EVs through p_t^{G2V} and p_t^{V2G}. The total EV demand d_t^{Tot} (kW), including the non-controllable load, is defined as

$$d_t^{\mathrm{Tot}} = D_t^0 N (1-\alpha) + p_t^{\mathrm{G2V}} - p_t^{\mathrm{V2G}} \qquad \forall t \tag{5}$$

where D_t^0 is the reference (non-demand response) profile given by ChaProEV (see Section **??**), and α is the proportion of vehicles that are optimally providing demand response.

Further modelling

The formulation Equation 1-Equation 4 has several shortcomings because there is no clear distinction between plugged and unplugged EVs. For example, suppose that plugged EVs were fully charged and the unplugged EVs were near to being empty, equation Equation 1 allows that unplugged EVs could be charging while they should be unavailable to the system.

(Momber et al., 2014) shows this and more detailed cases where the traditional EV aggregated formulation fails.

To overcome the above shortcomings, (Momber et al., 2014) proposed a more rigorous formulation, in which inventories for plugged/unplugged EVs are clearly distinguished from each other. This formulation ensures that only EVs plugged to the grid are charged/discharged from the electric system. It also guarantees that unplugged EVs cannot further charge while driving.

The state of charge of EVs in Equation 1 is now replaced by the separated plugged Equation 6 and unplugged Equation 7 state of charges. Additionally, Equation 2 is replaced by Equation 8 and Equation 9.

$$
\begin{aligned}
e_t^{\text{plugged}} =& e_{t-1}^{\text{plugged}} + \eta^{\text{G2V}} p_t^{\text{G2V}} \Delta - \frac{p_t^{\text{V2G}}}{\eta^{\text{V2G}}} \Delta \\
& + N_{t-1}^{\text{plugging}} N \alpha e_{t-1}^{\text{unplugged}} - N_{t-1}^{\text{unplugging}} N \alpha e_{t-1}^{\text{plugged}} \qquad \forall t && (6) \\
e_t^{\text{unplugged}} =& e_{t-1}^{\text{unplugged}} - E_{t-1}^{\text{drive}} \Delta N \alpha \\
& - N_{t-1}^{\text{plugging}} N \alpha e_{t-1}^{\text{unplugged}} + N_{t-1}^{\text{unplugging}} N \alpha e_{t-1}^{\text{plugged}} \qquad \forall t && (7) \\
\underline{E} N_t^{\text{plugged}} N \alpha \leq e_t^{\text{plugged}} &\leq \bar{E} N_t^{\text{plugged}} N \alpha \qquad \forall t && (8) \\
\underline{E} N_t^{\text{unplugged}} N \alpha \leq e_t^{\text{unplugged}} &\leq \bar{E} N_t^{\text{unplugged}} N \alpha \qquad \forall t && (9)
\end{aligned}
$$

Software innovations

No code parameters and profiles modification (explain what kind of modifications are possible) Scenarios

1. *Demand for next leg (kWh) (from network):* The charge that the vehicles leaving in the next time step need to pull from the network for the leg they are about to undertake, corrected by the charger efficiency.
2. *Demand for next leg (kWh) (to vehicles):* The part of the above that vehicles get. (E_t^{drive} in Equation (1))
3. *Connected vehicles:* The share of vehicles that are connected to a charger (N_t^{plugged} in Equation (2))
4. *Charging Power from Network (kW):* Maximum power that connected vehicles can potentially draw from the network. ($\bar{P}_t^{\text{G2V}}$ in Equation (1))
5. *Charging Power to Vehicles (kW):* Maximum power that can potentially go to vehicles go to vehicles (i.e. the same as above with a charger efficiency correction).
6. *Vehicle Discharge Power (kW):* The amount of power connected vehicles can discharge to the network.
7. *Discharge Power to Network (kW):* How much of that discharged power can go to the network. ($\bar{P}_t^{\text{V2G}}$ in Equation (1))
8. *Effective charging efficiency:* Ratio between charging power going to the vehicle and power coming from the network. This can vary in time, as the location of the charging vehicles (and thus the efficiency of the involved chargers) changes as they move around. (η^{G2V} in Equation (1))
9. *Effective discharging efficiency:* Same as above, but for discharging (it is the power going out of the vehicles divided by the power going into the network). (η^{V2G} in Equation (1))

ChaProEV also provides charging sessions (in case they are not obtained from energy system models). This provides another description of the system that could be used for models and analyses that focus on charging sessions rather than profiles (which are aggregates of such sessions). Sessions include (in addition the elements that a profile gets):

1. *Location:* Where the session takes place
2. *Start time:* At which moment the vehicles in the session can start charging (i.e. when they arrive).
3. *End time:* At which moment the vehicles in the session must stop charging (i.e. when they leave).
4. *Demand for incoming leg (kWh) (to vehicle):* How much the incoming vehicles have spent on the leg arriving to the session.
5. *Maximal Possible Charge to Vehicles (kWh):* How much the vehicles could charge if they used the available power during their whole session.
6. *Charge to Vehicles (kWh):* How much of the vehicles actually charge during the session. This is based on the charging strategy of the vehicles and can be used to derive a charging profile.
7. *Charge from Network (kWh):* The same as above, but corrected for charging efficiency (i.e. how much the network provides)

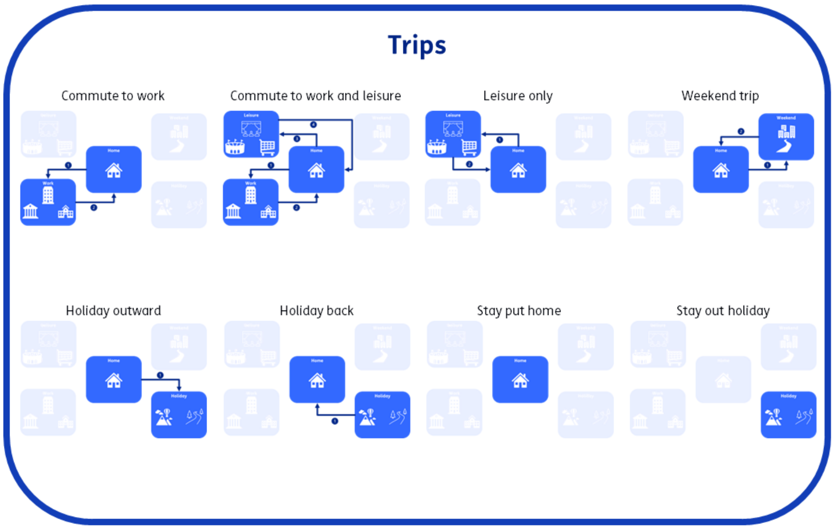

Figure 1: trips

Figure 1

Acknowledgements

ChaProEV was partly developed under funding from the European Climate, Infrastructure and Environment Executive Agency under the European Union's HORIZON Research and Innovation Actions under grant agreement no. 101095998.

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