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# ChaProEV: Generating Charging Profiles for Electric Vehicles

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## 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. –>

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

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

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

### Further modelling

The formulation **??**-**??** 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 **??** 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 **??** is now replaced by the separated plugged Equation 2 and unplugged Equation 3 state of charges. Additionally, **??** is replaced by Equation 4 and

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Equation 5.

$$
\begin{aligned}
e_t^{\text{plugged}} =& e_{t-1}^{\text{plugged}} + \eta^{\text{G2V}} p_t^{\text{G2V}} \Delta - \frac{p_t^{\text{V2G}}}{\eta^{\text{V2G}}} \Delta \\
& + N_{t-1}^{\text{plugging}} N \alpha e_{t-1}^{\text{unplugged}} - N_{t-1}^{\text{unplugging}} N \alpha e_{t-1}^{\text{plugged}} \quad \forall t \qquad (2) \\
e_t^{\text{unplugged}} =& e_{t-1}^{\text{unplugged}} - E_{t-1}^{\text{drive}} \Delta N \alpha \\
& - N_{t-1}^{\text{plugging}} N \alpha e_{t-1}^{\text{unplugged}} + N_{t-1}^{\text{unplugging}} N \alpha e_{t-1}^{\text{plugged}} \quad \forall t \qquad (3)
\end{aligned}
$$

$$
\underline{E} N_t^{\text{plugged}} N \alpha \le e_t^{\text{plugged}} \le \bar{E} N_t^{\text{plugged}} N \alpha \quad \forall t \qquad (4)
$$

$$
\underline{E} N_t^{\text{unplugged}} N \alpha \le e_t^{\text{unplugged}} \le \bar{E} N_t^{\text{unplugged}} N \alpha \quad \forall t \qquad (5)
$$

# 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. ($E_t^{\text{drive}}$ in Equation (**??**))
3. *Connected vehicles:* The share of vehicles that are connected to a charger ($N_t^{\text{plugged}}$ in Equation (**??**))
4. *Charging Power from Network (kW):* Maximum power that connected vehicles can potentially draw from the network. ($\bar{P}_t^{\text{G2V}}$ in Equation (**??**))
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 (**??**))
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. ($\eta^{\text{G2V}}$ in Equation (**??**))
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). ($\eta^{\text{V2G}}$ in Equation (**??**))

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).

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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)

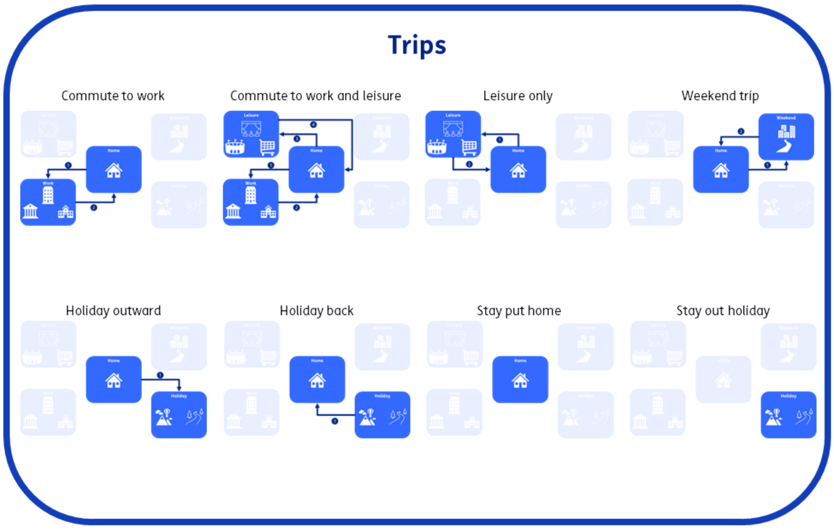


**Figure 1:** trips

Figure 1

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