# A RELIABILITY-AWARE DISTRIBUTED FRAMEWORK TO SCHEDULE RESIDENTIAL CHARGING OF ELECTRIC VEHICLES

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## Motivation

- Residential charging of electric vehicles (EVs) alters the average residential demand profile to a significant extent.
- Distribution system reliability requirements
  - node voltages within limits (0.95p.u. - 1.05p.u.)
  - line power flows less than line capacities.
- Challenge for the distribution system operator (DSO): Find the best schedule for residential EV charging, which
  - accommodates consumer personal preferences,
  - maintains network reliability, and
  - respects consumer privacy.

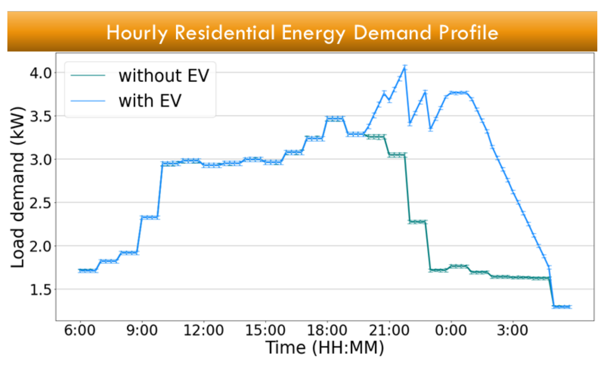



*Figure 1. Altered load profile with EV charging*

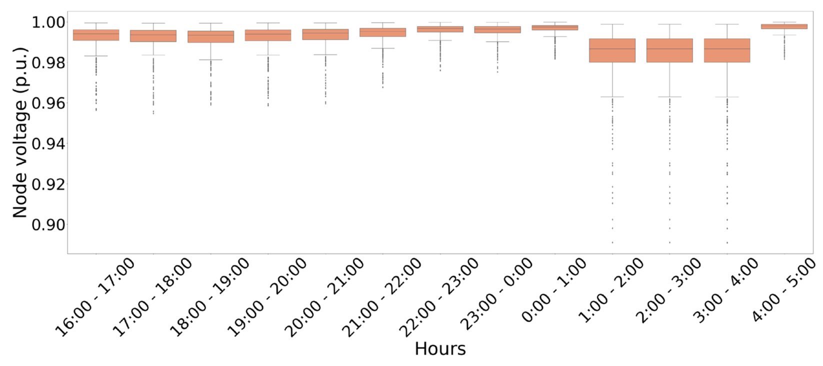
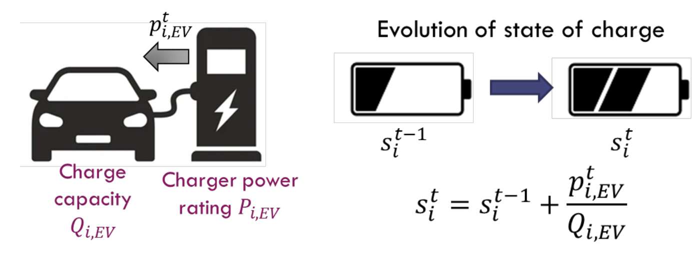



*Figure 2. Under-voltage when EVs are charged simultaneously*

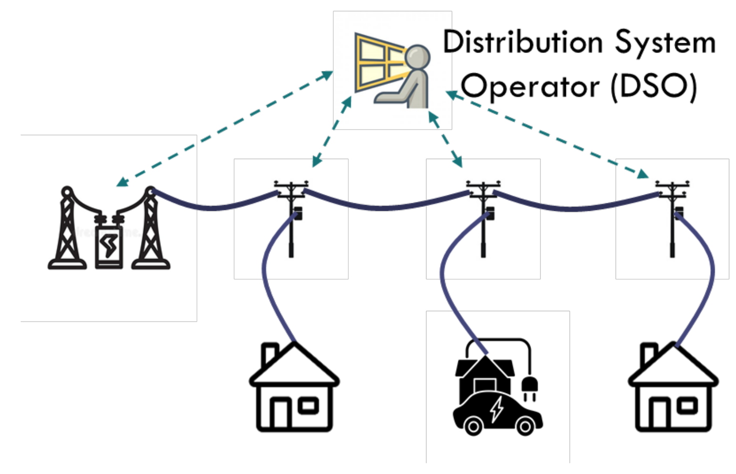
## Residential EV Charge Scheduling (REVS) Problem

**Consumer optimization (MILP)**




$$
\begin{aligned}
\min\ & \sum_{t=1}^{T} c_i^t p_i^t \\
\text{over}\ & p_i^t, s_i^t, z_i^t && \forall t \\
\text{s.t.}\ & p_i^t = p_{i,0}^t + p_{i,\mathrm{EV}}^t && \forall t \\
& p_{i,\mathrm{EV}}^t = z_i^t P_{i,\mathrm{EV}} && \forall t \\
& s_i^t = s_i^{t-1} + \frac{p_{i,\mathrm{EV}}^t}{Q_{i,\mathrm{EV}}} && \forall t \\
& z_i^t \in \{0,1\} && \forall t \\
& z_i^t = 0 \quad \forall t \le t_{\mathrm{start}},\ \forall t \ge t_{\mathrm{end}} \\
& s_i^{t_{\mathrm{start}}} = s_{i,\mathrm{init}},\ s_i^{t_{\mathrm{end}}} \ge s_{i,\mathrm{final}}
\end{aligned}
$$

**DSO optimization (LP or QP)**




$$
\begin{aligned}
\min\ & \sum_{t=1}^{T} C\left(\mathbf{p}^t\right) \\
\text{over}\ & \mathbf{p}^t \\
\text{s.t.}\ & \alpha \mathbf{1} \le -2\mathbf{R}\mathbf{p}^t + \mathbf{1} \le \beta \mathbf{1} && \forall t \\
& -\bar{\mathbf{f}} \le \mathbf{A}^{-1}\mathbf{p} \le \bar{\mathbf{f}} && \forall t
\end{aligned}
$$

## Approaches

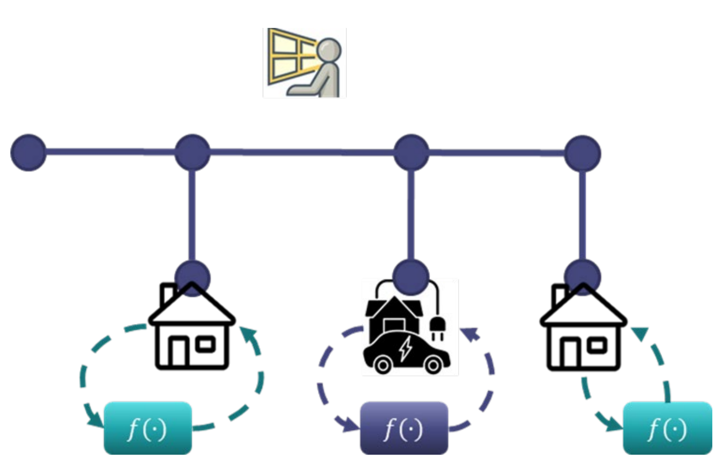


*Figure 3. Individual approach*

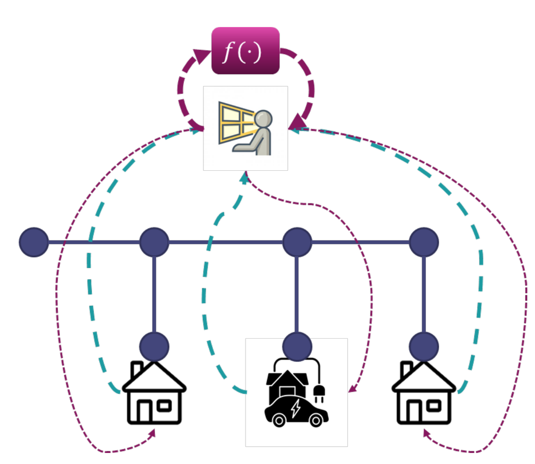


*Figure 4. Centralized approach*

Individual approach
- No information exchange.
- Each consumer solves own problem.
- Suboptimal or infeasible solution for DSO.

Centralized approach
- Consumers share information with DSO.
- Optimal solution guaranteed for consumers and DSO.

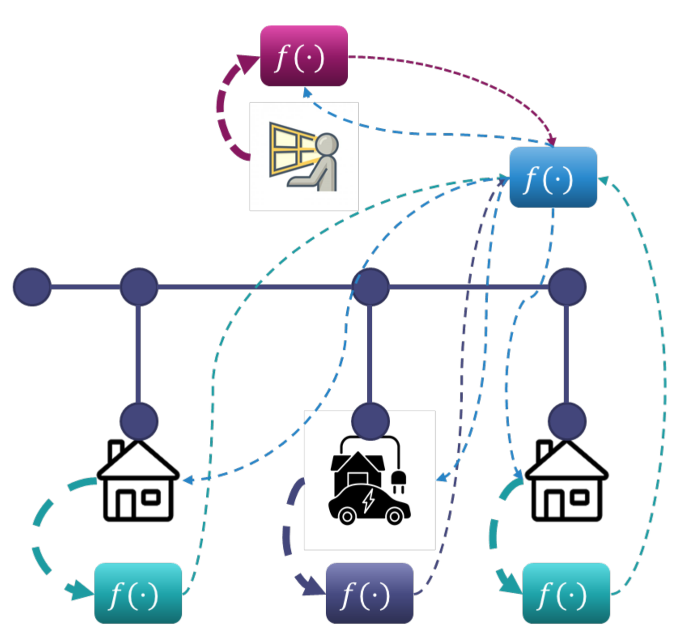


*Figure 5. Distributed approach*

Distributed approach
- Consumers and DSO solve own problem.
- Optimal solutions are exchanged to reach consensus.
- Sub-optimal solution for consumers and DSO.

## Proposed Distributed Approach

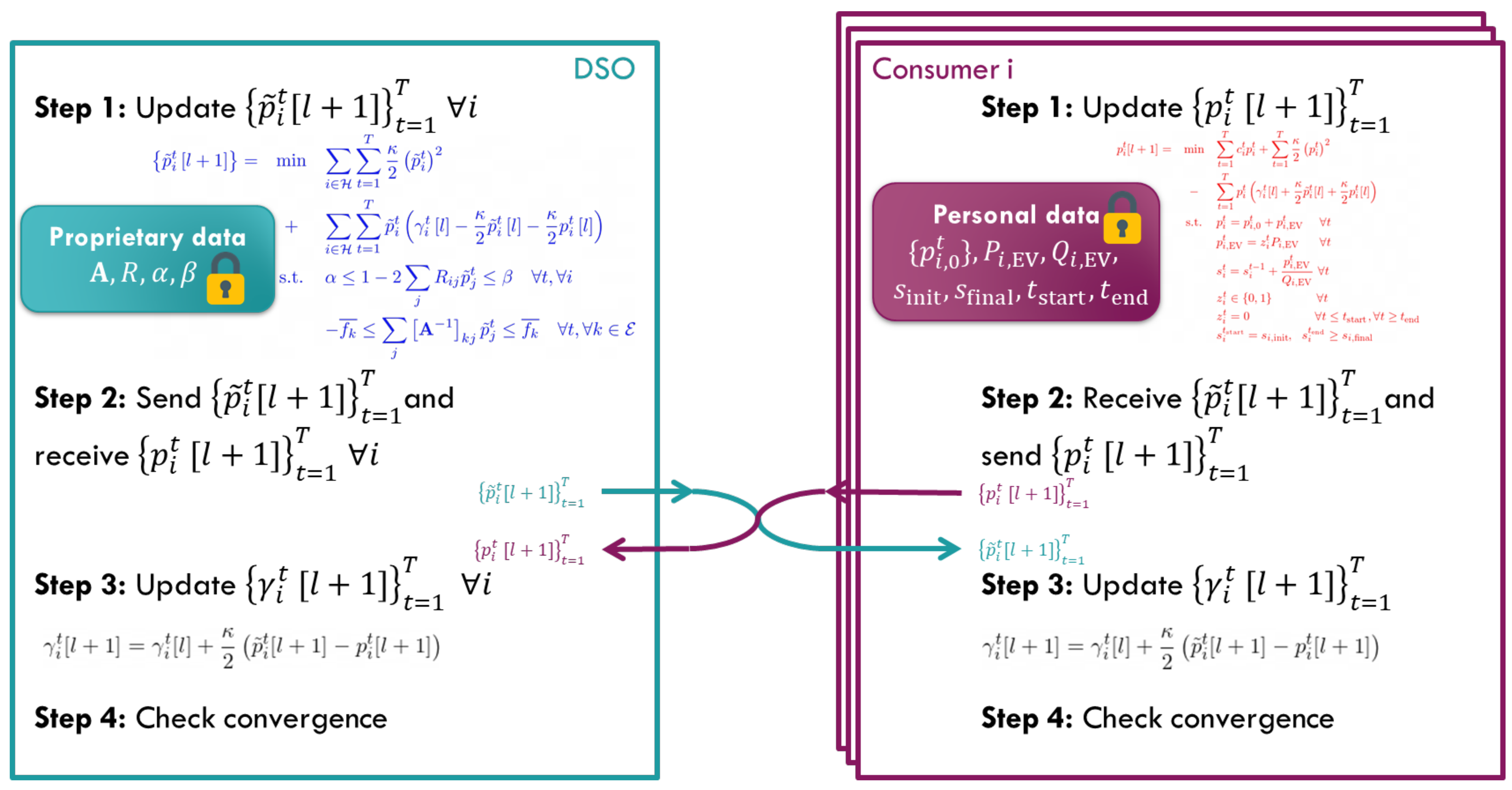



*Figure 6. Proposed distributed framework to schedule residential EV charging*

## Experiment Setup

| Time Interval (HH:MM) | Tariff ($/kWh) |
|---|---|
| 00:00 – 05:00 | 0.07866 |
| 05:00 – 15:00 | 0.09511 |
| 15:00 – 18:00 | 0.21436 |
| 18:00 – 00:00 | 0.09511 |

*Table 1. Electricity tariff*

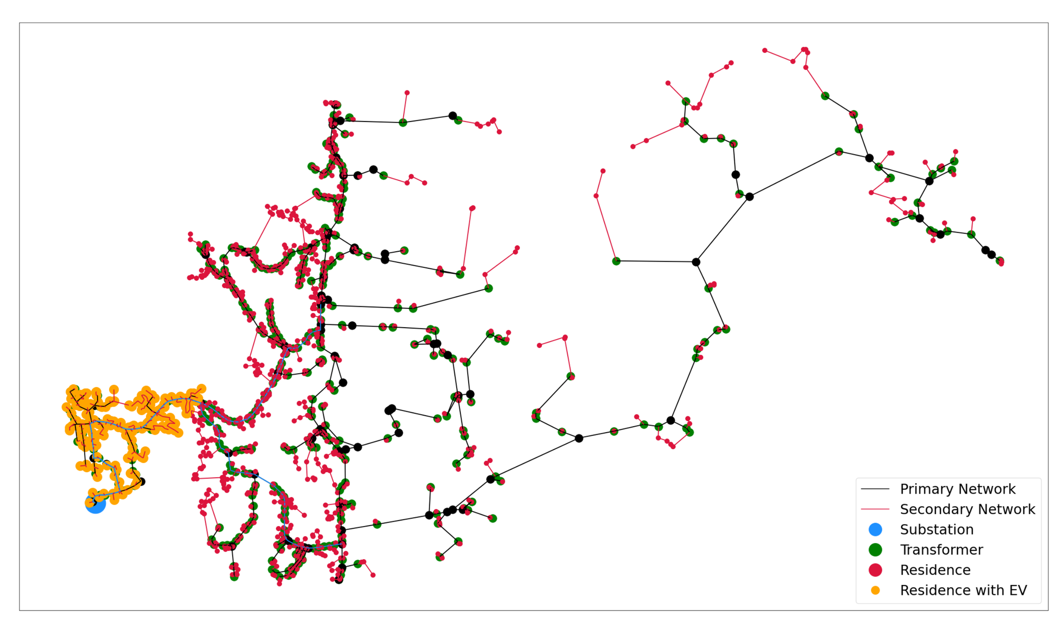



*Figure 7. Synthetic distribution network*

## Results

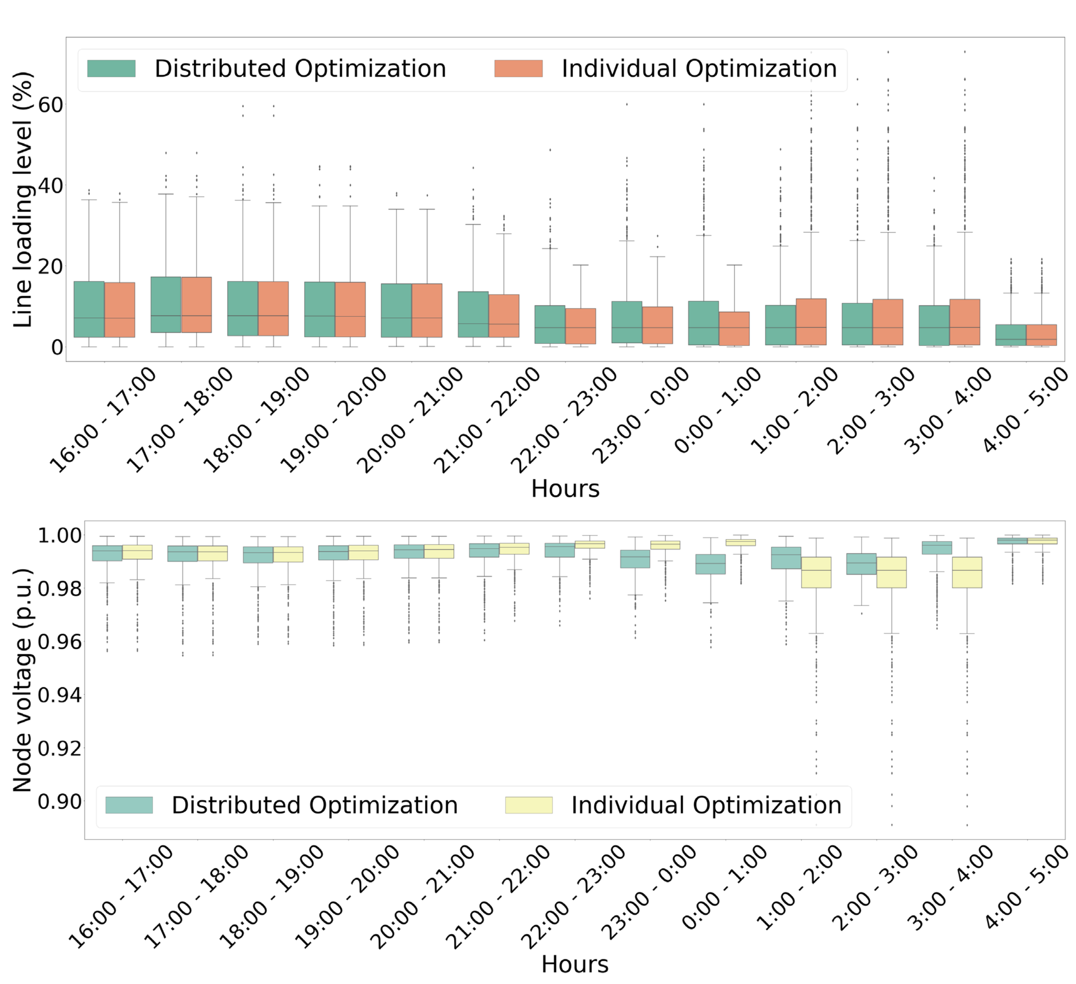



*Figure 8. Line loading levels and node voltages for residential EV charging with 90% adoption*

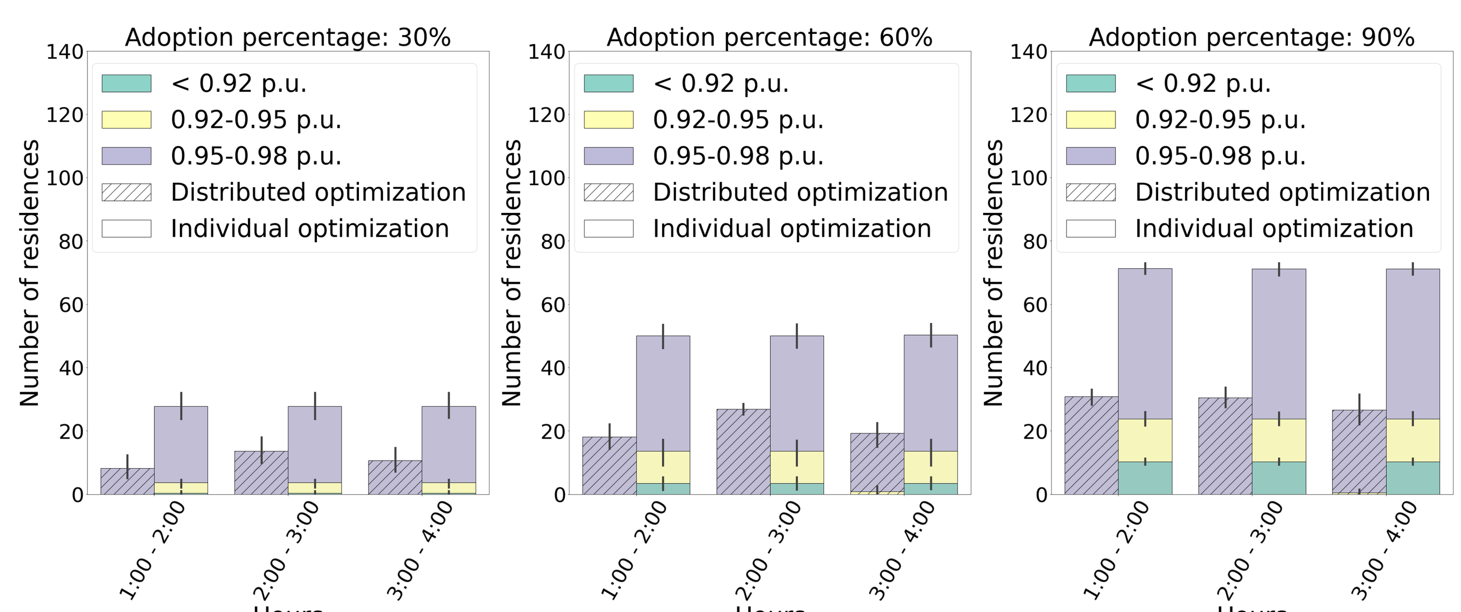



*Figure 9. Comparison of distributed and individual approaches of EV charging for different EV adoption in the distribution network*

## Concluding Remarks

- Distributed approach can accommodate high levels of residential EV charging without compromising on network reliability and consumer privacy.
- Upgrade in coordinating approaches is more beneficial than upgrading infrastructure

References

1.S. Boyd et al., Distributed optimization and statistical learning via the alternating direction method of multipliers. Found. Trends Mach. Learn.,3(1):1–122, Jan 2011.
2.R. Meyur et al., “A Reliability-aware Distributed Framework to Schedule Residential Charging of Electric Vehicles,” International Joint Conference on Artificial Intelligence (IJCAI): Special Track on AI for Good, Vienna, Austria, July 2022.
3.R. Meyur et al., “Ensembles of Realistic Power Distribution Networks," Proceedings of National Academy of Sciences (PNAS), Vol. 119, No. 42, 2022.