Evaluating the Impact Analysis of EVs and Heat Pumps on the Primary-Secondary Distribution System Using Real-World Data

Authors: Priyanka Lama, Salish Maharjan, Anne Kimber, and Zhaoyu Wang*

Presenter: Priyanka Lama

Email: plama@iastate.edu

10/11/2024

IOWA STATE UNIVERSITY

Introduction

- Growing adoption of **Electric Vehicles (EVs)** and **Heat Pumps (HPs)** is reshaping residential electricity consumption.
- Significant challenges for **distribution grid utilities**, particularly **transformer overloading**.
- Analyze the impact on transformer overloading in distribution grids.

Objective:

- Assess the impact of EV charging and HP integration on service transformer (ST) overloading.
- Evaluate seasonal variations and penetration levels of EVs and HPs in the residential context.
- Identify overload patterns to inform utility strategies.

Methodologies

- **Data Sources and Data Types**
  - Smart meter data with 15-minute AMI resolution of residential customers and EVs from multiple utilities in the **Midwest USA**. (EV Chargers level-1 and level-2 types, with power ratings ranging from 0.56 kW to 15.7 kW)

- **Data Classification**
  - Classified the cleaned data into four seasons: Spring(Mar-May), Summer(Jun-Aug), Fall(Sep-Nov), and Winter(Dec-Feb)
  - Identify daily patterns of EV Charging and Consumption behavior.

- **Simulations:**
  - Used Monte Carlo simulations for comprehensive impact analysis.

EV Charing Behavior Analysis

- **Daily Frequency**:
  - Similar distribution across all seasons with high probability of single charging sessions.
  - Significant chance of no charging sessions.
- **Plug-in Times**
  - Peaks: 21:00 – 22:00(Spring, Summer, Winter)
  - Morning peaks in fall (4:00-5:00)
- **Charging durations**
  - Most common: 1-2 hours.(shorter duration)
  - Rarely exceeds 5 hours.

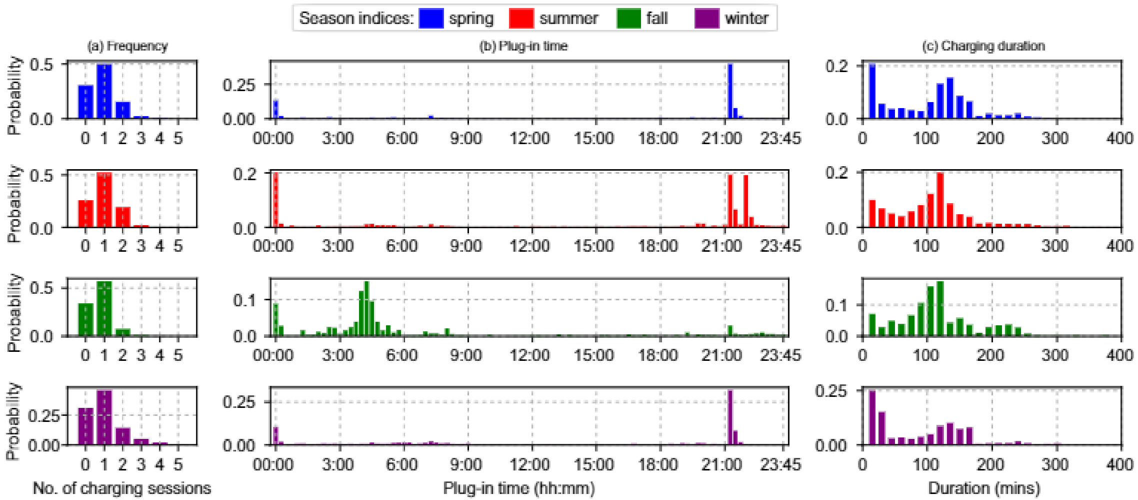

Fig: Probability distribution of EV charging behavior in terms of (a) frequency of charging sessions, (b) plug-in time. and ©charging duration.

Load Profiles with and without HPs

- **Typical load profiles of residential customers using K-means clustering method.**
  - Five clusters identified.
  - Seasonal variations of consumption profiles.
  - Evening peaks for non-HP users in spring/summer; morning/evening for fall/winter.
  - HP users show significantly higher demand with peak demand upto five times than the

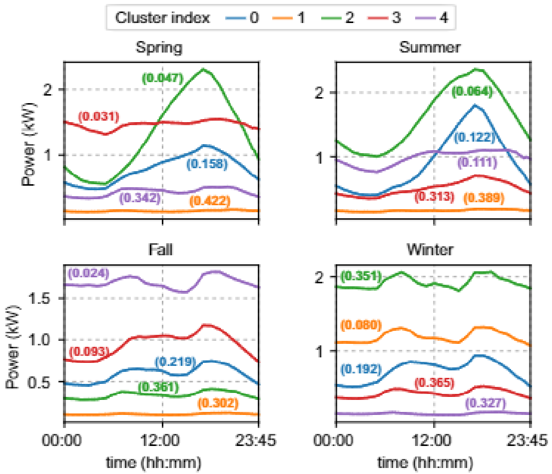

Fig: Daily load profile of residential customers without heat pumps.

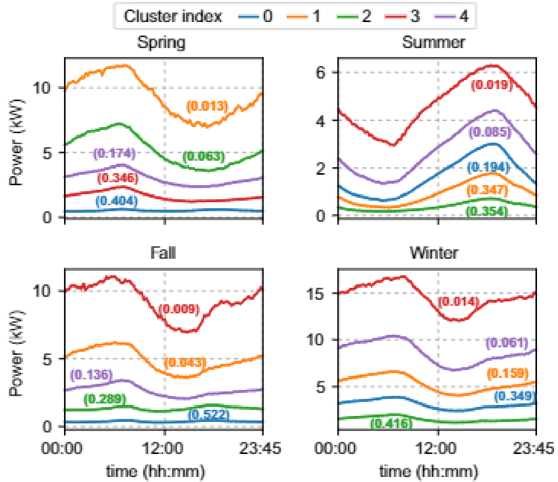

Fig: daily load profile of residential customers with heat pumps.

Scenarios of EV Charging Demand

- **Charging Scenarios**
  - Charging frequencies.
  - Aggregated demand from multiple EV profiles.

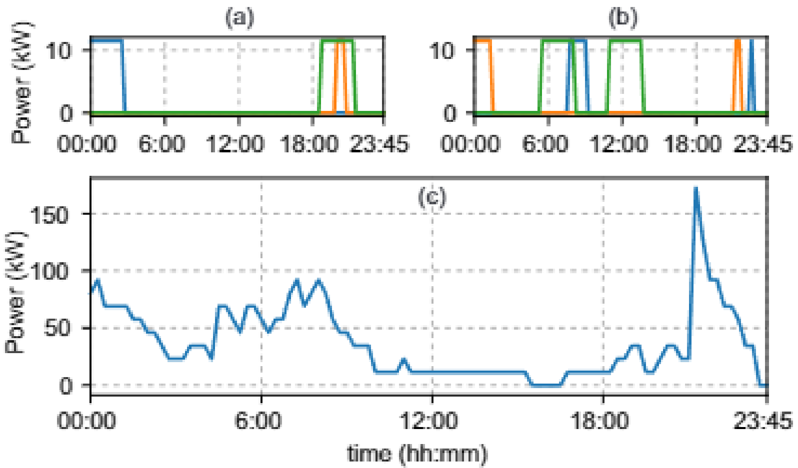

Fig: samples of EV charging demand for (a) and (b) two charging frequencies. (c) Aggregated EV demands of randomly generated EV charging profiles.

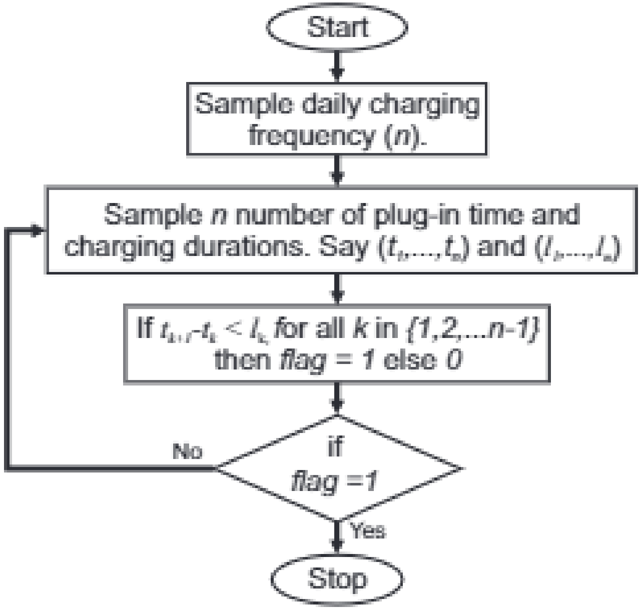

Fig: Sampling process for EV charging scenario generation.

ST Overloading Analysis

- We leveraged the OpenDSS model of a primary-secondary distribution feeder, shown in Fig.
- To study the impacts of EV and HP penetration, we randomly selected residential customers from the feeder shown in Fig. 2 to create various penetration cases.
- As we increased the penetration levels, the customers already selected at previous levels were retained.

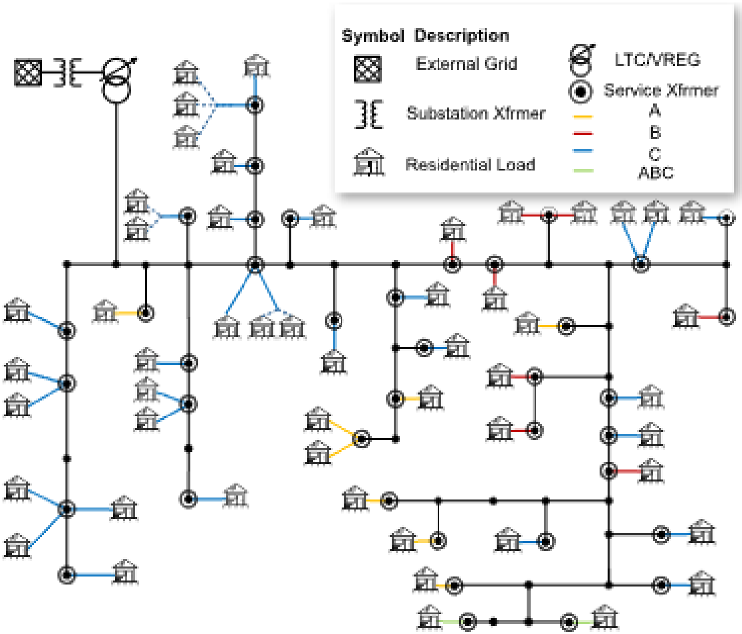

Fig: Real primary-secondary distribution network

Penetration Impacts

Penetration Levels: 25%, 50%, 75%, 100% for EVs and/or heat pumps.

- **EV Penetration**:
  - Overloading increases with penetration.
  - ST overloading more severe in summer compared to other seasons. (evening peaks in residential consumption with the most probable plug-in time.)
- **HP Penetration** :
  - Significant impacts in winter at all penetration levels. (high heating requirement.)
  - Minimal impacts in summer.(HP profile is below 6 kW for a single residential home.)
  - Climate in Iowa does not require excessive cooling resulting lower HP energy consumption.

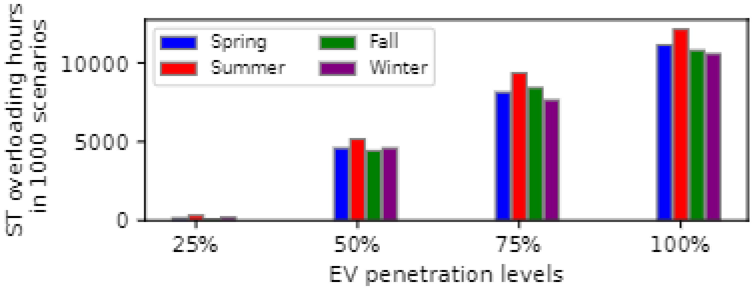

Fig: EV penetration impacts on ST overloading hours.

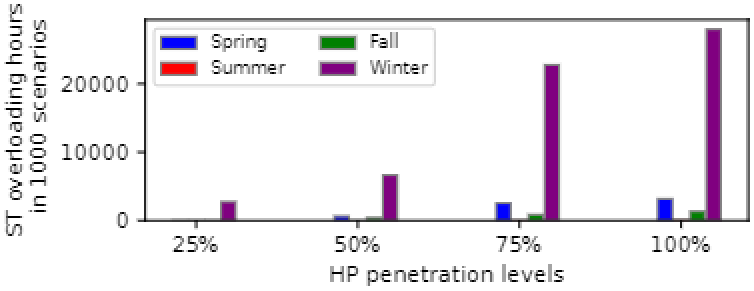

Fig: HP penetration impacts on ST overloading hours.

Combined Penetration Impacts

- **Results**:
  - HP impacts dominate over EVs, especially in winter.
  - Winter shows the significant impacts compared to other seasons.

- **Critical Overloading Periods:**
  - Highlighted periods account for 90% of ST overloading.
  - Winter: 18:00 to 11:00 the following morning.
  - Summer: 17:00 to 9:00.

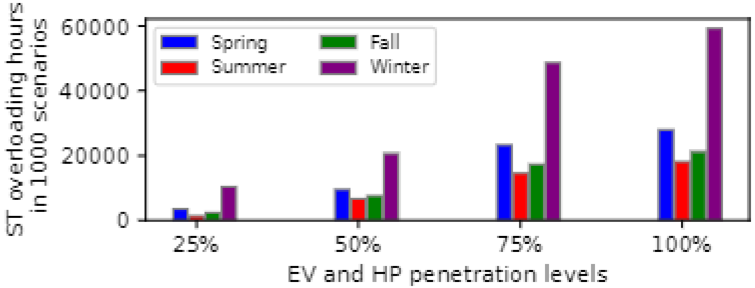

Fig: EV and HP penetration impacts on ST overloading hours.

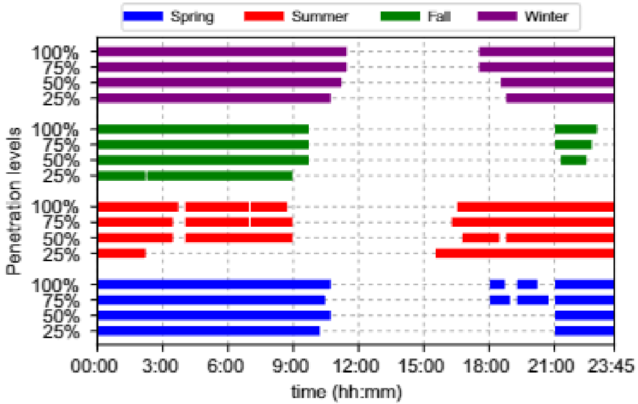

Fig: Time span showing 90% of ST overloading at various seasons.

Conclusion

- EV and HP penetration significantly affect ST overloading.
- Importance of seasonal considerations in managing overloading risks.
- Data-driven insights inform utility tariff structures.
- Significance: Implications for Utilities
  - Contributes to understanding how evolving residential electricity demands affect grid operations.
  - Supports the development of adaptive management strategies to maintain grid reliability and service quality.
  - Adaptive strategies:
    - Time-of-use tariffs.
    - Infrastructure upgrades.

Thank You!
Q&A