User Instructions and Sample Output of the Transformer Overloading Evaluation Tool with EV and Heat Pump Penetrations

The development of this tool was funded by the Iowa Energy Center project 22-IEC-3 “Mining Smart Meter Data for Modeling and Mitigating EV Charging Impacts on Distribution Grids”

IOWA STATE UNIVERSITY

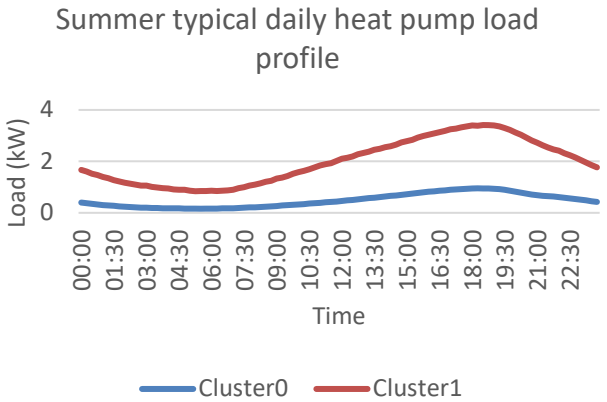
Tool Overview

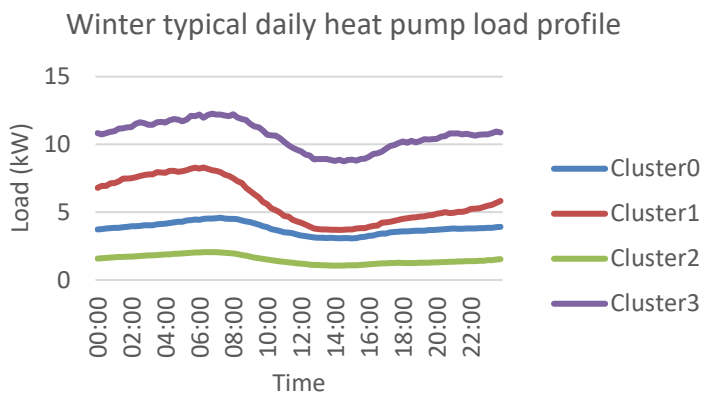
- **Partners**: ISU, Algona Municipal Utilities, Linn County REC, Mi-Energy Co-op, Cedar Falls Utilities, IA DOT.
- Analyze real EV charging and heap pump data and evaluate the impact on the distribution grid, which could benefit our utility partners.
- Used sub-metered heat pump and EV charging data, and aggregated SM data containing EV users to achieve the following tasks:
  - Analyze EV charging demands and derive typical EV charging and heat pump patterns.
  - Develop an open-source tool for utilities to evaluate annual distribution transformer loading conditions with selected penetration levels of EV and Heat pumps.

Data Type	Provider
Sub-metered EV charging	Mi-Energy Co-op
Sub-metered heat pump	Linn County REC
Aggregated SM	Linn County REC, AMU, CFU

Derive Typical EV Charging and Heat Pump Patterns

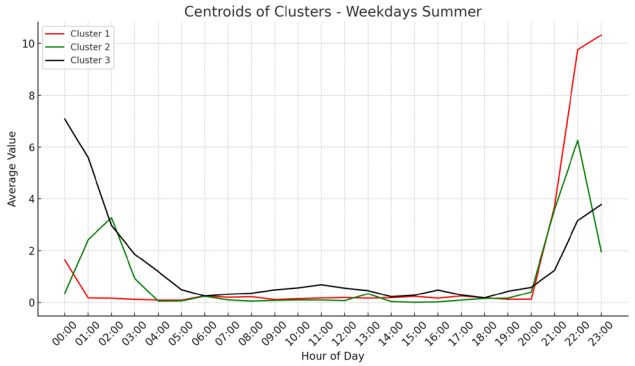
- Using sub-metered EV charging and heat pump data, explore EV charging behavior variations between seasons and compare behavior between workdays and weekends.
- Data segmentation and clustering to extract seasonal representative load shapes for EV and heat pumps.
- Cluster probability represents the frequency of each typical profile being selected during the data sampling process.





Cluster	Probability	Customers
0	0.8015	1519
1	0.1985	377

Cluster	Probability	Customers
0	0.242	461
1	0.085	160
2	0.644	1219
3	0.0299	56



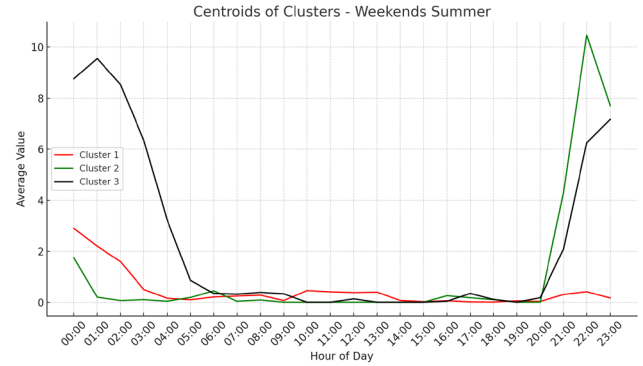


Fig. EV charging clusters for summer weekdays and weekends

Method of Assessing Transformer Overloading

- Use Monte-Carlo Simulation and sample the heat pump and EV charging profiles using the extracted seasonal typical curves with **different penetration levels** of EVs and heat pumps. Calculate the final aggregated load for each customer with corresponding smart meter data.
- Integrate aggregated load with utility models considering transformer-customer connectivity to calculate the distribution transformer **thermal loading condition** and evaluate **overloading duration and intensity**.
- Open-source tool available for utilities to evaluate annual DT thermal loading conditions with chosen EV and heat pump penetration levels.

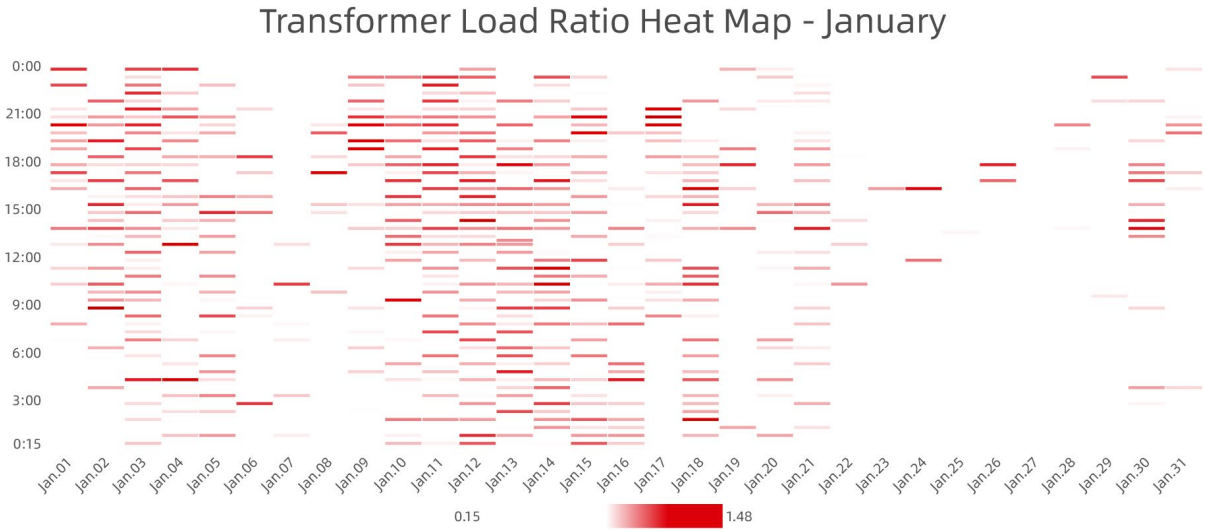


Fig. Loading ratio heat map of specific transformer in a month

How This Tool Works

1. Data Validation:
   - Ensures that the transformer data (RAW_TC.xlsx) contains required fields (e.g., MTR_ID, XFMR_ID, XFRM_SIZE).
   - Checks AMI data (RAW_AMI.xlsx), including valid timestamps and cross-references meter IDs with transformer data.
   - Confirms that AMI data covers a full annual cycle.
2. Data Transformation:
   - Converts transformer sizes to kVA and kW using a predefined power factor.
   - Assigns numerical customer indexes based on meter IDs.
   - Restructures AMI data to classify time-based features like seasons, weekdays/weekends, and hourly demand patterns.
3. Load Profile Assignment:
   - Randomly selects customers for EV and HP profiles based on predefined penetration levels.
   - Assigns seasonal load patterns using probability-based sampling from pre-defined cluster profiles.
   - Generates merged load profiles by adding EV and HP consumption patterns to AMI data.
4. Overloading Evaluation:
   - Calculates the total load for each transformer by summing up the loads of its connected customers.
   - Identifies peak transformer loads and timestamps of maximum demand.
   - Counts occurrences where transformer loads exceed their rated capacity on an annual and monthly basis.
   - Outputs results into structured Excel files with multiple sheets for easy interpretation.

How to Prepare the Input Data

You can refer to the sample data provided. Or follow this instruction:

1. Preparing Transformer-Customer Data (RAW_TC.xlsx). This file contains essential transformer information and its associated customers. Ensure the following columns are correctly formatted:

Column Name	Description	Format
MTR_ID	Unique meter ID assigned to each customer	String (e.g., '12345678')
XFMR_ID	Unique transformer ID associated with the meter	String (e.g., 'T-101')
XFRM_SIZE	Transformer capacity in kVA or coded format	Numeric (e.g., '50') or coded string ('50_1PL')

- Ensure all MTR_IDs are unique and consistent.
- Assign correct XFMR_IDs to their respective meters.
- XFRM_SIZE must be a numeric value or coded format (e.g., '50_1PL').
- No empty cells or missing values.
- Ensure column names are exactly as specified.

How to Prepare the Input Data

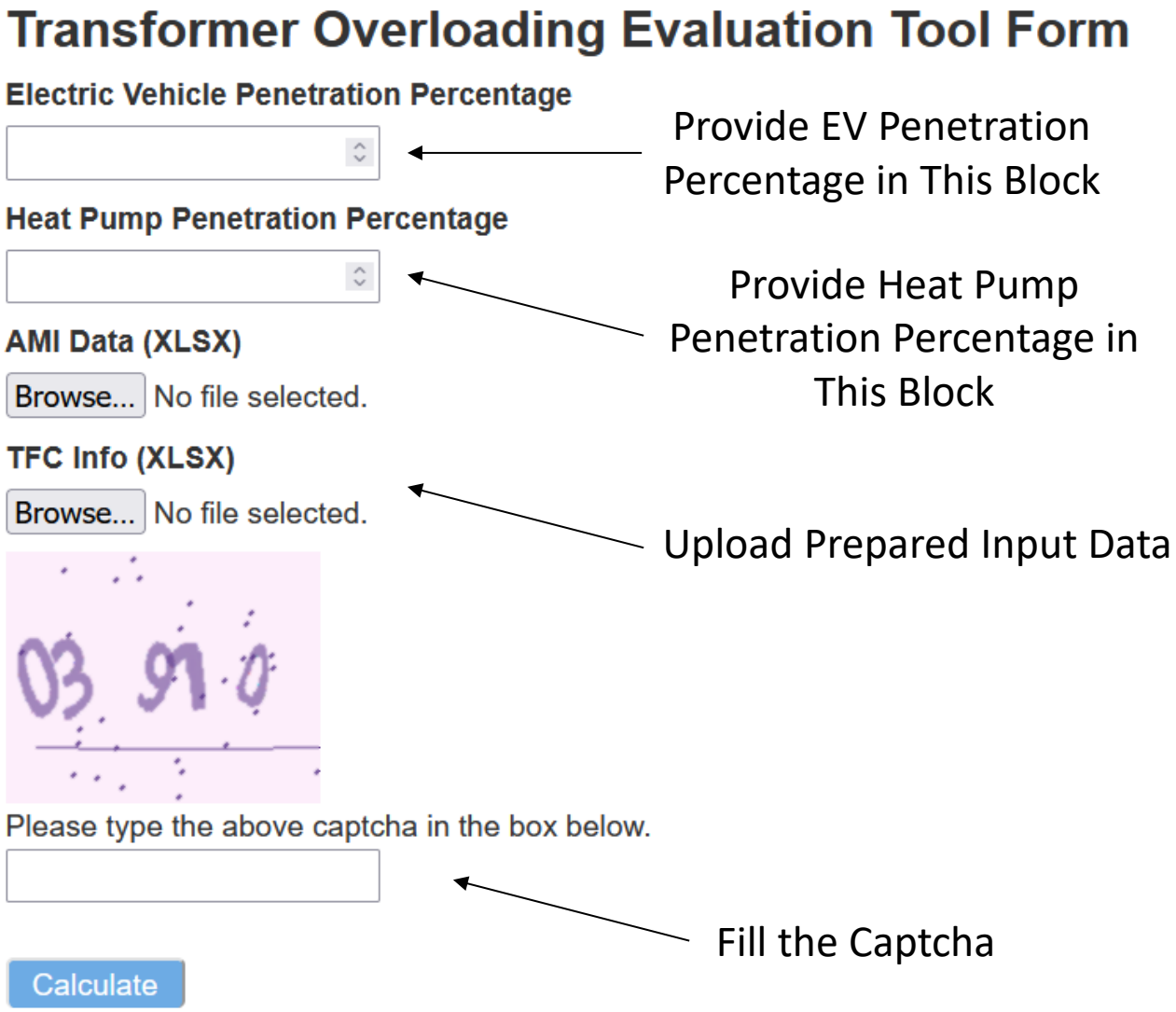
You can refer to the sample data provided. Or follow this instruction:

2. Preparing Smart Meter Data (RAW_AMI.xlsx). This file contains the hourly power consumption data of customers over a full year. The following columns must be included:

Column Name	Description	Format
Time	Timestamp of hourly readings	Datetime ('YYYY-MM-DD HH:MM')
Meter ID 1	Hourly energy consumption for customer 1	Numeric (kW)
Meter ID 2	Hourly energy consumption for customer 2	Numeric (kW)
…	…	…

- The first column must be named 'Time' and contain 8760 hourly entries or 8784 hourly entries (for leap years).
- All meter IDs must match those in RAW_TC.xlsx.
- No missing values allowed.
- Ensure timestamps are continuous and sequential.

How to Interact with the UI



- The user defines a penetration level to indicate how many customers have EVs and heat pumps.
- By running the algorithm over again, the results yield differently, because:
  - The algorithm randomly selects customers and aggregates EV and heat pump data.
  - The algorithm uses the clustering probabilities to assign corresponding EV and heat pump profiles with respect to different seasons and day types (weekdays/weekends).

Example Results of DT Load Condition Analysis

Transformer	Transformer Capacity (kW)	Annual Overloads > 100% of capacity	Annual Overloads > 120% of capacity	Annual Overloads > 140% of capacity
1	1350	0	0	0
2810	13.5	5	0	0
2912	13.5	2	0	0
2913	13.5	0	0	0
2914	13.5	0	0	0
2917	13.5	50	4	0
2919	22.5	0	0	0
2923	22.5	1	0	0
2926	22.5	18	3	0
2930	9	0	0	0
2934_3597	31.5	0	0	0
2936_7089	42.75	0	0	0
2984	13.5	17	3	0

Annual peak load, time, and overload counts (hours).

Monthly breakdown for each transformer.

Transformer	Transformer Capacity (kW)	Month	Monthly Overloads > 100% of capacity	Monthly Overloads > 120% of capacity	Monthly Overloads > 140% of capacity	Max Monthly Load (kW)	Date of Max Monthly Load
2810	13.5	1	0	0	0	9.912	2024-01-05 Hour: 5
2810	13.5	2	2	0	0	13.652	2024-02-26 Hour: 0
2810	13.5	3	3	0	0	14.044	2024-03-15 Hour: 0
2810	13.5	4	0	0	0	12.747	2024-04-13 Hour: 2
2810	13.5	5	0	0	0	10.998	2024-05-28 Hour: 6
2810	13.5	6	0	0	0	11.275	2024-06-10 Hour: 5
2810	13.5	7	0	0	0	11.99	2024-07-21 Hour: 5
2810	13.5	8	0	0	0	10.994	2024-08-30 Hour: 4
2810	13.5	9	0	0	0	10.637	2024-09-05 Hour: 4
2810	13.5	10	0	0	0	12.558	2024-10-13 Hour: 2
2810	13.5	11	0	0	0	12.639	2024-11-25 Hour: 2
2810	13.5	12	0	0	0	12.534	2024-12-03 Hour: 2

Thank You for Using This Tool!