AI for Weather Compensation and Load Prediction at 11kV/240v Electrical Substations throughout the Cheshire & Warrington LEP Region

E. O'Malley, Prof. J. Wu, Dr. D. Pugh, Prof. P. Bowen, Cardiff University Dr. D. Clements EA Technology.
EPSRC CENTRE FOR DOCTORAL TRAINING IN RESILIENT DECARBONISED FUEL ENERGY SYSTEMS
[Grant number EP/S022996/1]

KAUST Research Conference: AI for Energy
6-8 March 2023

Introduction

The purpose of this work is to understand the effect of the weather, specifically temperature on power/current loads at *11kV/240v* substations.

This can inform a predictive model that differs for each substation to assist load forecasting and to validate measures suggested as part of a demand side management (DSM) strategy.

This work has been conducted in collaboration with *EA Technology*, with the data being captured from their *VisNet® Hub* LV monitoring device (monitors the 240v network). Datasets used have a resolution of half-hourly measurements.

Figure 1: *Images of VisNet® Hub installed in a substation*

Depending on the end-users and devices connected to a given circuit, the load at a substation level will be influenced.

The dataset is composed of measurements from 600+ substations (11kV/240v) within the Cheshire and Warrington Local Enterprise Partnership (LEP).

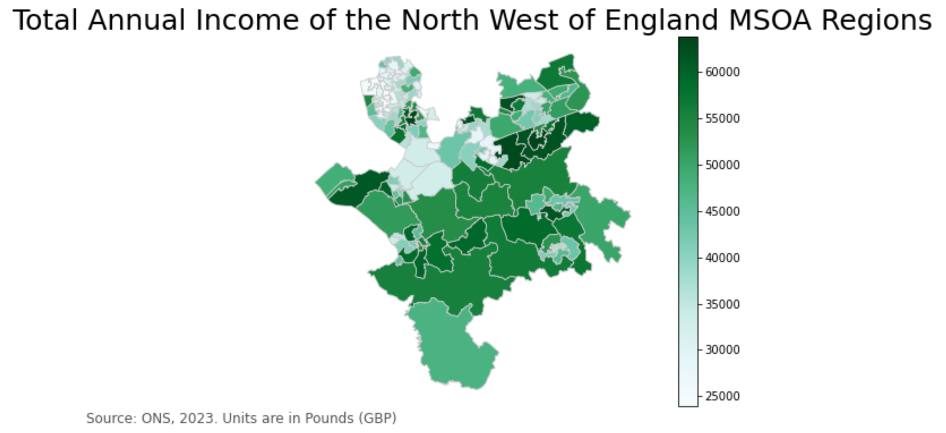

Figure 2: *Household Total Annual income within the LEP region*

The area varies in socio-economic make-up:

- ***Ellesmere Port*** has large industrial areas and low-income domestic properties
- ***Chester*** is an upmarket, historic city with high-income housing and numerous commercial retail units
- ***Cheshire Oaks***- a 337000 sq ft outlet shopping centre with multiple substations. Has a high heating and cooling load
- ***Rural Villages***- high-income areas, high number of EVs (electric cars)
- ***Suburban areas***- high income housing with high number of EVs

Case study: NationalGrid Demand Flexibility Service (DFS)- code was written to quantify the reduction in power consumption during a time interval that NationalGrid incentivised demand reduction (when national demand is at a peak). The weather compensation/load prediction model will be used to validate the results.

Methodology

Python scripts analysed the load data and the geographical location of the substations were mapped out, along with the nearest Met Office and amateur weather stations.

The nearest neighbour algorithm was used to assign each substation a nearest weather station to identify which weather dataset should be used for modelling. Met Office Data was obtained through the Met Office Datapoint API and the amateur data was captured through a web weather scraper.

The load data was normalised against the concept of "Heating Degree Day" (HDD) values based on the average temperature at the substation on a given day. HDD was calculated using a simplistic average method, along with an integral methodology using hourly temperature measurements as follows:

$T_{reference}$ is a *reference temperature*; any external temperature below this reference a building requires heating. In the UK $T_{reference}$ is commonly set at 15.5°$_C$.

$$(1)\ Simple\ HDD = T_{reference} - \frac{T_{external,min} + T_{external,max}}{2},\ (Simple\ HDD < 0 \rightarrow 0)$$

$$(2)\ Interval\ Difference = T_{reference} - T_{external},\ (Interval\ Difference < 0 \rightarrow 0)$$

$$(3)\ Integral\ HDD = \frac{\sum Interval\ Difference}{Number\ of\ Intervals}$$

Integral HDD was used thereon due to increased accuracy.

HDD values were joined with the daily average load for each phase and way within each substation throughout the historic timeframe and was plotted using 'MatplotLib'.
A linear relationship was fitted using 'Sklearn', with the line gradient indicative of the sensitivity of the substation to temperature change.

To reduce the effect of weekends on the gradient, only weekdays informed the model.

Gradient values were classified as outliers if greater than 3 standard deviations from the mean value.

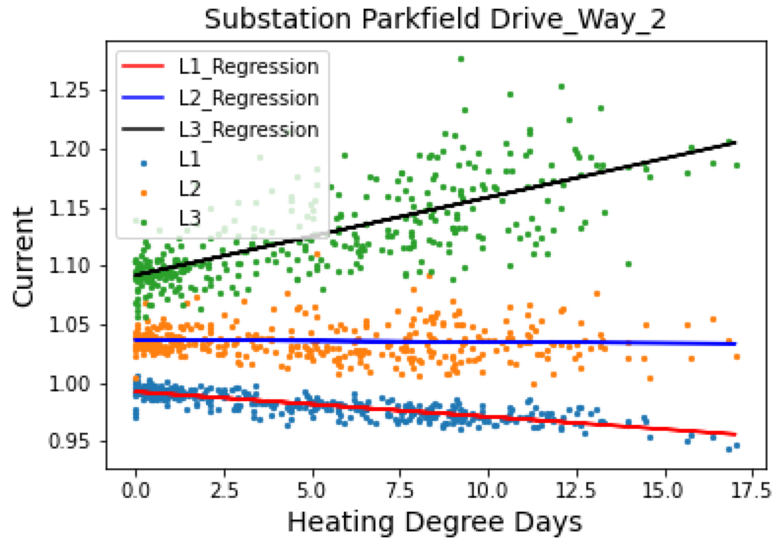

Figure 3: *Plot of Current (3 Phase) vs HDD for one substation way*

Case study: the model to quantify DFS savings was developed by comparing the Power consumption at a given interval, to that of the 14 previous weekdays. Power consumption at each interval was calculated with the root-mean-squared (RMS) Power reading.

The percentage difference was calculated for each individual interval and then the combined percentage difference was calculated for the entire DSM interval, with an average value for each substation.

Results

Temperature Gradient Results:

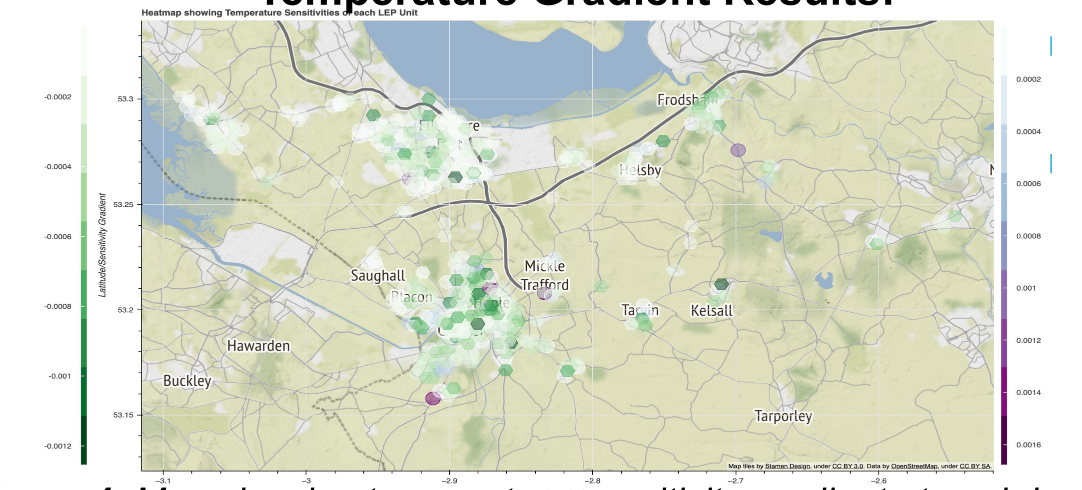

Figure 4: *Map showing temperature sensitivity gradient at each location*

The calculated **Temperature Sensitivity Gradients** for each substation is shown on the heatmap. The **majority of locations display negative gradient** i.e. with decreased temperature load increases. A **minority of substations have a noticeable positive gradient (inverse behaviour)**, due to high cooling demands in summer months. The **greater the magnitude of the gradient, the greater sensitivity to change due to ambient temperature.**

NationalGrid DFS Case Study Results:

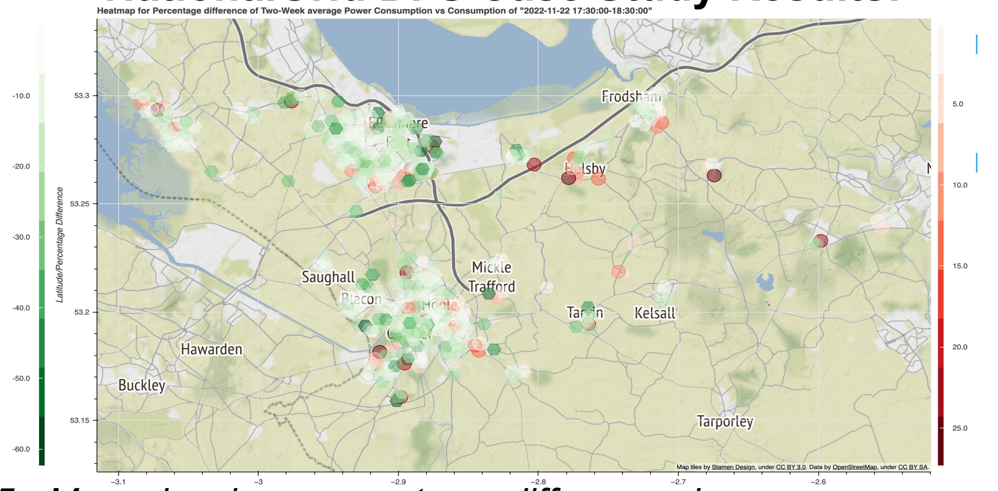

Figure 5: *Map showing percentage difference in power consumption at each location*

The ***Total Percentage Difference*** in power consumption during a period of DFS incentivisation is shown. Substations exhibited a **maximum reduction of consumption of 60%**. Substations exhibited a **maximum increase in consumption of 25%**. Significant reductions in commercial/light industrial units in Chester, Ellesmere Port and business parks. Reductions also occur in neighbourhoods within Neston, Ellesmere Port and Chester suburbs.

Summary

This work successfully allows the calculation of historic half-hourly loads for each substation based on a given date. Most importantly, it can predict future half-hourly loads (current and total power) for each substation for an estimated temperature profile.

The work has investigated external factors that influence power consumption, both on a macroscopic scale with variables such as the weather and ambient air temperature. Microscopic variables that change the demand, have also been explored in the form of the "NationalGrid DFS" case study.

The sensitivity parameters vary for each "way" and phase of every substation so can provide a specific value to each substation location. This model is best applied to residential substations and commercial/light industrial units as "heavy industrial" substations exhibit uncharacteristic behaviour.

Interactive visualisations using the Folium and Bokeh Python Libraries have been created to understand how the results vary with substation location and socio-economic factors.

Ongoing Work

Validation of the code used in the demand reduction case study is ongoing and quantifying that the quoted reduction is due to the demand measures and not coincidental. Using the weather-load model, a probability distribution for each half hourly load will be created for a given temperature and will be normalised against the temperature of that day.

Exploration of further small and large scale influences of Power Consumption to make the model more accurate.

Development of a Digital Twin and Artificial Intelligence model to predict power consumption at each substation.
Digital Twin purpose: Load planning, maintenance scheduling and system to trial DSM measures.