Electrical Grid Management

IEDA4000B Group Project: Richard Blažek, Tik Long Bryan Yeung

Problem

The problem we decided to solve is managing an electrical grid with renewable energy sources. Our grid consists of a wind power plant and a backup consisting of a gas power plant and a battery. The wind turbine generates a volatile amount of electrical power, which can be predicted from meteorological data. The gas power plant can generate enough electrical power to cover all of the demand for electricity, but it needs two hours to ramp up production. The battery can supply electricity immediately, but it has limited capacity - part of our project is determining how large a battery we need to build.

Our approach

We have a dataset from Kaggle on historical meteorological data and wind electricity generation (https://www.kaggle.com/datasets/mubashirrahim/wind-power-generation-data-forecasting) for every hour over about five years. We split the dataset into three parts — training (60 % of the dataset), validation (30 %) and simulation (10 %). The three parts are contiguous, rather than being randomly shuffled, because the three sub-datasets would not make sense if not as a series in time.

Training

We are using the first part for training a MLP regressor from the scikit-learn package in Python to predict wind electricity generation based on meteorological data two hours ago (so that we have two hours to ramp up gas-based electricity production).

Validation

Our regressor scored R-squared of 0.9467 on the data. Then we calculated prediction errors for the regressor on our prediction dataset. We interpret the prediction errors as a random normal variable with mean zero and we can estimate their standard deviation based on our sample — degrees of freedom is the number of the weights of our regressor.

The battery needs to be large enough to cover the prediction errors, so we should build a battery of size six times the standard deviation (so that there is only about twice in a billion chance of exceeding the capacity). For our data, the standard deviation is 0.0637, so we have to build a battery of size 0.3821.

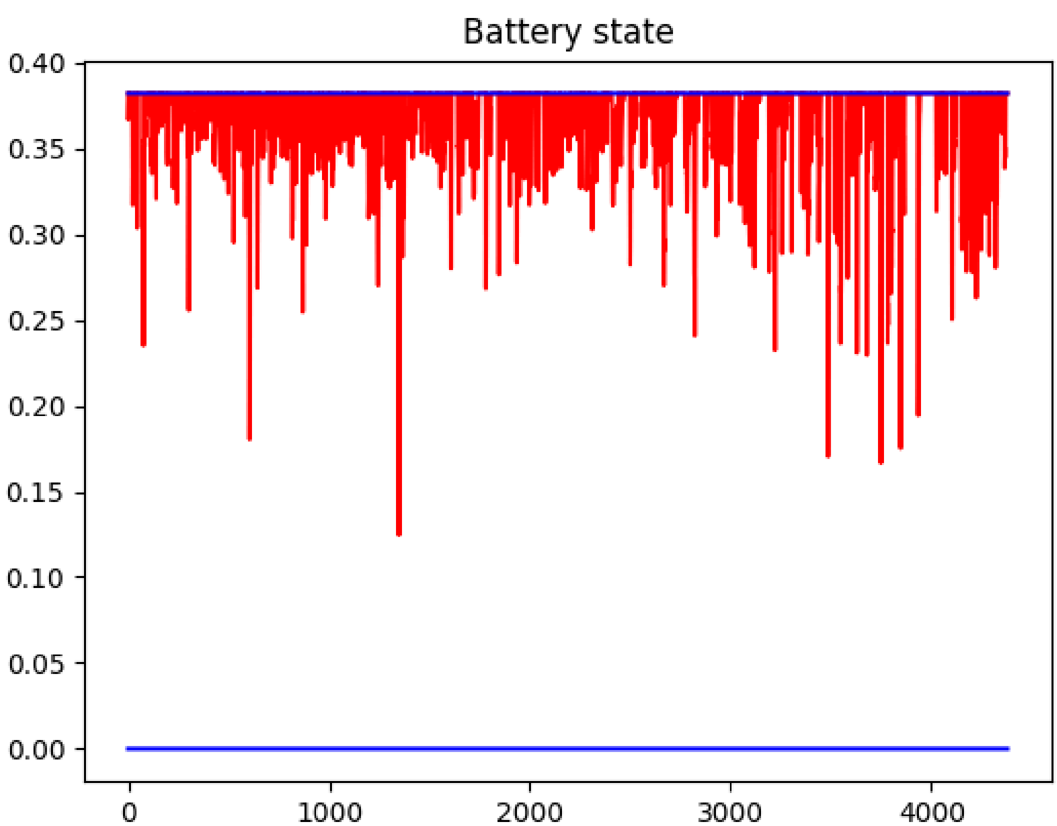
Simulation

We simulate our grid on the data spanning around 182 days, that is half a year. We assumed the demand for electricity to be constant for simplicity, but incorporating volatility of demand would not be much of a change, it would only require adding one more MLP regressor for

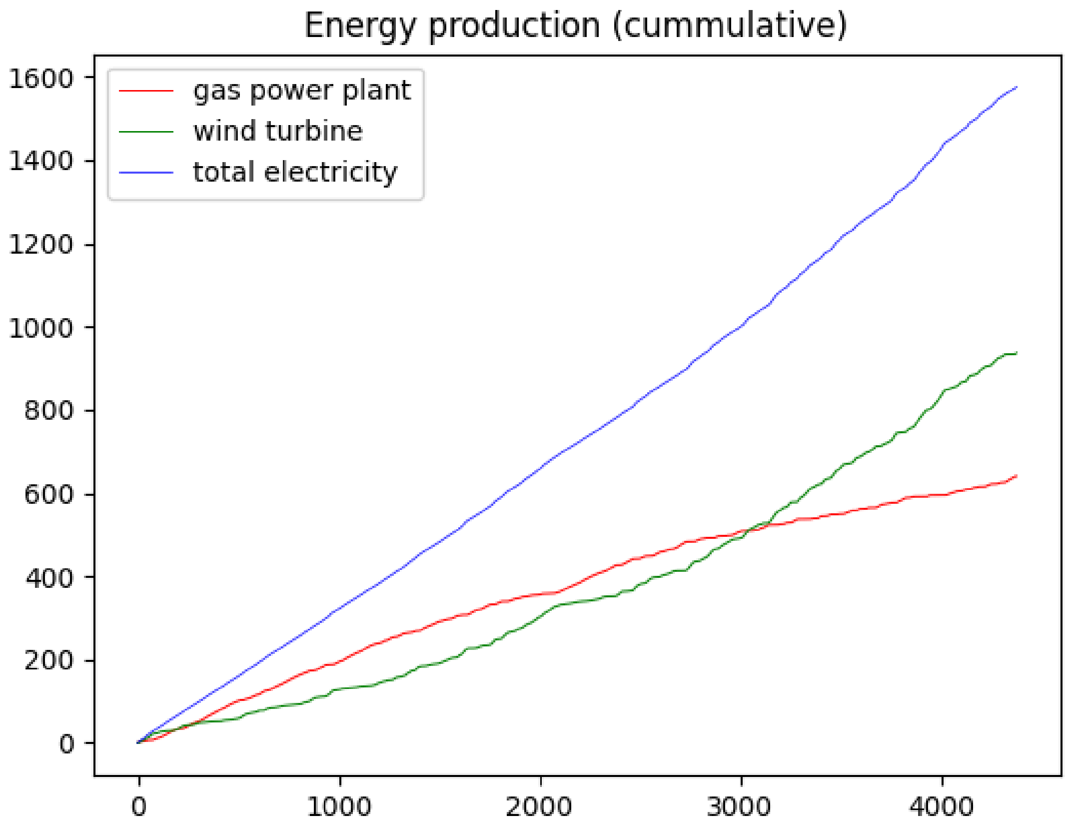
predicting demand and considering prediction errors for demand. In real-world grids, the demand is more stable and predictable than the supply, so if we can handle fluctuations in power generation, the demand volatility can be added more easily.
In each step, we use the regressor to predict wind power generation. That is used to determine how much power to generate from gas. We aim to cover the demand and also recharge the battery. Then we look into the dataset to see how much power the wind turbine really generated. If the total power generated (wind and gas) is lower than the demand, we take the rest from the battery. If it is greater, we store it in the battery. If the battery is fully charged, we ignore excess energy, because both gas power plants and wind turbines can ramp down power generation quickly (curtailment).

Results

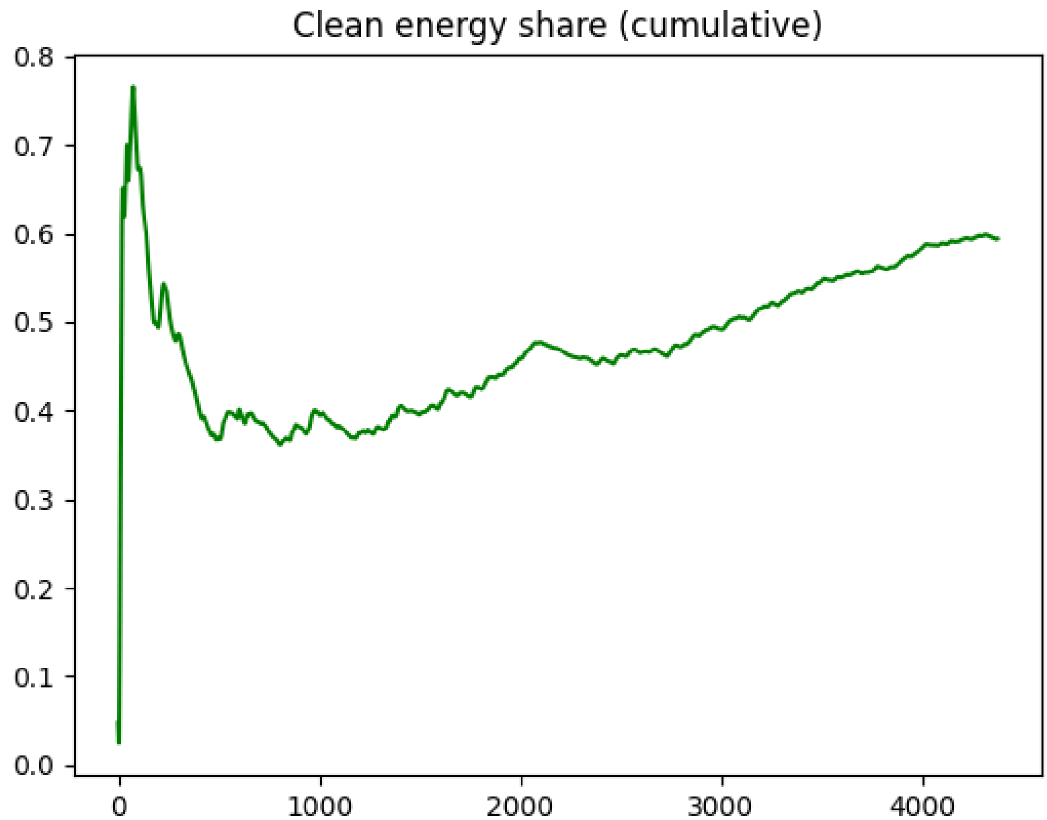
We ran our simulation, collected statistics and plotted these charts.



The battery size we chose was sufficient for covering the prediction errors. This shows that our formula for determining how large a battery to build worked well. Also, our algorithm for predicting wind power generation and determining how much electricity to make from gas was successful.



We can see how the relative share of gas and wind varied over time. We can see that in different times, we covered different shares of energy from wind or gas.



Overall, we covered about 60 % of energy from the wind turbine.

Further improvements

We could change our algorithm to minimise overproduction to reduce excessive gas consumption. However, that might require larger batteries or better prediction. Also, we could generalise our power grid to handle more power sources with different properties, not just three.