Statistical modelling for energy security of supply

Amy Wilson

University of Edinburgh

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Electricity systems

- Formed of capacity (gas, wind, solar, storage, interconnection, hydro...), transmission and distribution (plus other assets).
- Electricity demand is the amount of electricity required by consumers.
- NESO must provide generation to meet the demand required minute-by-minute, 24 hours a day.
- Very little ability to move electricity through time (batteries, hydro power, flexible demand). Needs to be enough capacity to meet the max demand in a year.
- Some actions NESO can take if shortfall is expected.
- Cutting off consumers is extremely damaging politically and economically.

Capacity adequacy studies

- Electricity generating plants take many years to build.
- Risk of insufficient supply to meet demand must be assessed years in advance so that action can be taken.
- GB has an annual 'capacity assessment study' (done by NESO) looking at risk of shortage of supply.
- Study informs how much capacity to procure in Capacity Market Auction (worth $\sim$ £1bn per year).

Capacity adequacy in the news

Ofgem

Ofgem warns of blackouts as it predicts grid's spare capacity could fall to zero

Regulator says demand-supply cushion risks being wiped out in 18 months, prompting consultation on further subsidies to keep power stations open

Terry Macalister

Friday 17 July 2015
19.42 BST

Shares
249

Save for later

UK faces second winter with dearth of spare power capacity

Christopher Adams, Energy Editor

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Britain's creaking electricity system faces a second winter with an uncomfortably slim safety cushion of spare power capacity, forcing National Grid to again buy in emergency supplies to combat the risk of blackouts.

The margin of capacity over demand is expected to be 5.1 per cent this winter, the grid has disclosed in a consultation document for power generators, compared with last year's 4 per cent, which was the lowest level in seven years.

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Electricity blackouts would cause 'severe economic consequences'

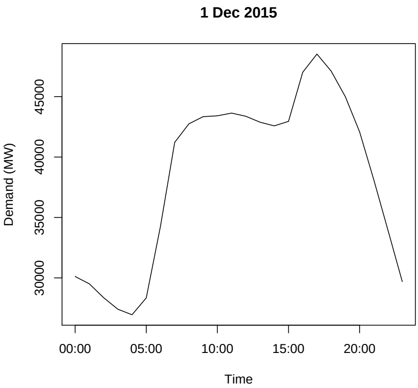
By John Moylan
Industry correspondent, BBC News

27 November 2014 | Business

GB system

- Winter peaking system
- Peak demand: 55-60GW
- Installed wind: 30GW
- Installed solar: 17GW

Typical winter day:



Risk assessment

- In GB, use Loss of Load Expectation (LOLE) and expected energy unserved (EEU) as risk metrics.
- LOLE is expected number of hours that there will be an electricity shortfall over one year.
- Expected energy unserved is expected shortfall in energy supply over one year.
- Reliability standard is LOLE$=3$.
- LOLE and EEU are estimated four years ahead, for each of a set of ‘Future Energy Scenarios’.
- Based on these results, amount of capacity to be procured in T-4 auction (i.e. 4 years ahead) is decided.

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Statistical problem

- How to estimate loss of load expectation?
- Loss of Load Expectation (LOLE):

$$\sum_{t=1}^{m} P(D_t > X_t + W_t + I_t),$$

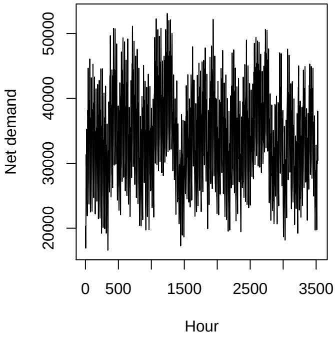
for D_t =demand in hour t, X_t =supply in hour t from conventional generators (e.g. gas, coal, nuclear), W_t =wind generation in hour t, I_t = interconnection in hour t, m hours in year.

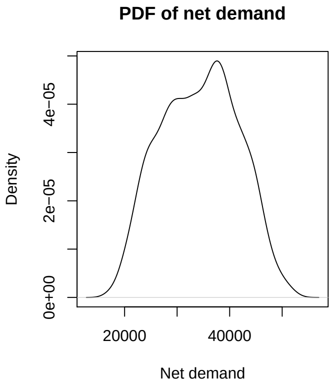
- Joint model needed for D_t, X_t, I_t and W_t.
- Also include storage and solar but these have a much smaller effect.
- No transmission constraints considered - aggregate GB wind/demand/conventional generation modelled.

Data

- Historical demand data, rescaled to future year/scenario under study using an estimated ‘year effect‘ called ACS peak. Estimate of distributed generation added on.
- Capacities and availability probabilities for all conventional generating plants in future year/scenario. Availability probabilities estimated using historical data.
- Wind generation 'data'. Formed from wind speed reanalysis data (MERRA) combined with model for wind farms in place in future year/scenario.
- Model for interconnection based on a conditional probability distribution outputted from an energy system model.

Time-collapsed model





Current approaches: non-sequential model. Does not model correlations through time.

Time-collapsed

- Non-sequential, or 'time-collapsed' - choose random point in time.
- Doesn't model correlations through time, frequency/ duration of shortfalls. OK as only estimate LOLE and not much storage.
- Two state distribution for each generator - on or off with set probability (dependent on type of generator). Convolution to get distribution of X.
- Assumed distribution of interconnection conditional on being in a period of high demand. Will drop interconnection now for simplicity.

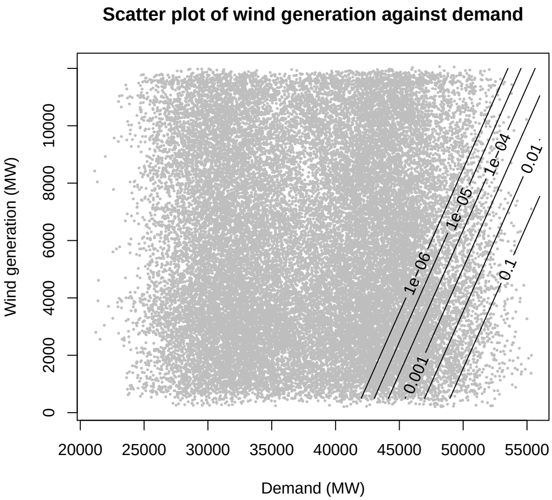
Hindcast approach

$$\text{LOLE} = \frac{1}{n_y} \sum_{t=1}^{n} P(X \leq d_t - w_t),$$

for observed wind-demand pairs (d_t, w_t), where n_y is number of years in dataset.

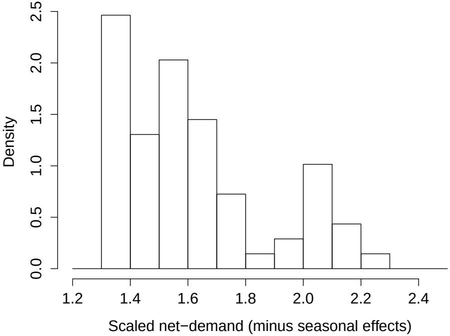
- Hindcast makes no assumption on the form of the distribution of $D - W$.
- There are few observations in the tail of $D - W$ (high demand and low wind).
- Hindcast estimates will depend heavily on these few observations
- The most extreme possible value of net-demand is assumed to be the most extreme *observation* of net-demand.

Limited data



Smoothing

Instead can use parametric model to smooth data in tail. Extreme value theory provides asymptotic theory for this smoothing.



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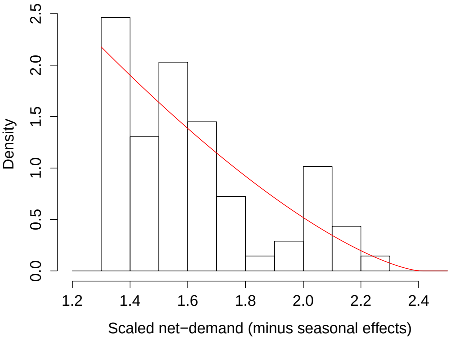

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Why is re-scaling needed?

- Project 2 part 2 is focussed on the demand modelling. How do we get dataset of demand (d_t for $t \in \{1, \ldots, n\}$) to use with the hindcast approach?
- Can't use the historical measurements directly as want to predict the LOLE for future year and we know there are trends in demand:
  - Population changes
  - Energy efficiency
  - Economic growth/ decline
  - Technology change
  - etc...

How can modelling help?

- Need a model that allows us to strip out trends in demand and add back in estimated trends for whichever future year we want to study.
- Can then either use re-scaled historic measurements (by stripping out estimated historic trend and adding future estimate back in).
- Or could use the model directly to generate a dataset appropriate for the future year.

Example year effect

Could fit linear regression model

$$D_{it} = \alpha + \beta_i + \epsilon_{it},$$

for $\epsilon_{it} \sim N(0, \sigma^2)$, for the t-th day in the i-th year of the historical dataset (n years).

- This model is treating year as a categorical variable.
- Here, $\hat{\beta}_i$ would be the fitted year effect for historic winter i.

Example year effect 2

- Let β_f be the assumed year effect for the future year under study. We could rescale the historic data as:

  $$d_{it} - \hat{\beta}_i + \beta_f.$$

  If we had n historic years of data, this would give us n re-scaled years to use in the hindcast calculation.
- Alternatively we could generate data from the fitted model by sampling from the residual distribution:

  $$\hat{\alpha} + \hat{\beta}_f + \epsilon_{it}$$

  But would need to be confident in the fitted distribution of the residuals.

Challenges in demand modelling

- Many challenges!
- Time effects (demand tends to be higher when the days are shortest and on certain days of the week).
- Temperature effects (demand tends to be highest when it is coldest).
- Large dataset - everything is statistically significant. Trade off simplicity with complexity.
- Confounding - confounding between the year effect and the other covariates may be problematic if you want to re-scale.
- Complex correlations between the various variables.

Tip: keep the application in mind

- You may come up with a new and exciting method, but can it deal with the year-effect? Will NESO be able to use it with their subjective future year effect estimates? Feel free to suggest ways they could do this.
- We are doing long-term demand modelling, so the objective is to be able to get generated or re-scaled demand data that can be used for computing the LOLE or for studying broad long term summary statistics in demand (e.g. max in year or 95% quantile).
- Issues that are important for short-term forecasting may not be relevant.