Electricity demand forecasting and the problem of embedded generation

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Operating the system

- Electricity National Control Centre
Operating the system

Generation          Demand

50.0 Hz

50.0 Normal operating frequency
50.5 Upper statutory limit
52.0 Generators tripping
49.5 Lower statutory limit
48.8 Demand disconnection starts
47.0 Demand disconnection complete
Demand profile shapes

- Shape of demand curves – in terms of turning points and points of inflections - remains **fairly constant from day to day**

- Exact position of turning points, both in vertical (Demand) and horizontal (Time) directions varies, at least partially because of weather and non-weather variables

- Shape evolves slowly over time, with some abrupt discontinuities
GB National Demand
A Typical Daily Profile: January

Winter Peak ~ 56,000 MW
Winter Minimum ~ 32,000 MW
GB National Demand
A Typical Daily Profile: January

Winter Peak ~ 56,000 MW

Winter Minimum ~ 32,000 MW
GB National Demand
A Typical Daily Profile: February

Winter Peak ~ 56,000 MW
GB National Demand
A Typical Daily Profile: March

Winter Peak ~ 56,000 MW
GB National Demand
A Typical Daily Profile: April

Winter Peak ~ 56,000 MW
GB National Demand
A Typical Daily Profile: May

Winter Peak ~ 56,000 MW
GB National Demand
A Typical Daily Profile: June

Winter Peak ~ 56,000 MW
GB National Demand
A Typical Daily Profile: June

Winter Peak ~ 56,000 MW
Summer Maximum ~ 40,000 MW
Summer Minimum ~ 20,000 MW
Forecasting electricity demand

- Typical demand profile shape

- 2 distinct shapes: GMT and BST
What Else Affects Demand?

- Time of Day
- Bank Holidays
- School Holidays
- Day of Week
Day of week impact

Demand curve for weekday in GMT

Demand curve for Saturday in GMT

Demand curve for Sunday in GMT
What Else Affects Demand?

- Time of Day
- Day of Week
- Bank Holidays
- School Holidays
- Weather
- Special Events
- TV
Temperature

COLD
High Demand

MILD
Low Demand

HOT
Quite High Demand

Demand Effect (MW) vs. Temperature

17
Illumination

- **Demand Effect (MW)**
  - **DULL**
    - High Demand
  - **BRIGHT**
    - Low Demand

- **Radiation**

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**National Grid**

18
The Impact of Weather
Cooling Power of the Wind

- Low Wind: Low Demand
- Strong Wind: High Demand

![Diagram showing the relationship between wind speed and demand.](image)
The Impact of Weather
Rain
The Impact of Weather
Some Numbers

Temperature
(1° C fall in **cold** conditions)

Cloud cover
(clear sky to thick cloud)

Precipitation
(no rain to heavy rain)

Temperature
(1° C rise in **hot** conditions)

Cooling power
(10 mph rise in **cold** conditions)

+ 500 MW

+ 1,500 MW

+ 1,000 MW

+ 500 MW

+ 1,000 MW
Weather Variables

- 4-Hourly Average Temperature [TO]
- Effective temperature [TE]
- Wind Speed [WS]
- Cooling Power of the Wind [CP] – a function of Wind Speed and Temperature (TO)
- Effective illumination of the Sky [EI] - A derived quantity calculated from radiation levels and measurements of cloud type and cover
Non-weather variables

- **Day of week**

- **Year Effect** – indicator variable for different years: mostly owing to different economic conditions

- **Time of year** – seasonality

- **Time of Sunrise and Sunset**

- **School Holidays** - % of schools on holiday

- **Annual Holidays** – indicator variable from common August holiday weeks

- **Bank Holidays** – excluded from data set for purposes of modelling, then deal with on an ad hoc basis
GB National Demand
Cardinal Points

1B

2B

DP
Standard Linear Regression
Conventional Models

Model Inputs:

- Historic Demands
- Historic Weather – Heathrow, Glasgow, Manchester, Bristol, Leeds, Birmingham
- Additional Effects – School Holidays, Day of Week, Time of Year
Modelling

- Construct different models for each of the Cardinal Points (CPs)
- Construct different models for GMT and BST
- Construct models of two different types for each CP:
  - Standard linear regression models (Conventional Models)
  - Time series models with linear regression (Trend models)
- Depending on the CP we construct 7 day models, 5 day models, Saturday models and Sunday models
- On any day of the week there are at least two (and up to four) models that we forecast with
2B Demand (12:30)
2B Model On Day Of Week Effect
Actual Demand Vs Fitted Values

[Graph showing actual demand vs fitted values with a model residual plot in the background]
Including A Seasonal Effect
Actual Demand Vs Fitted Values

In the diagram, we see a time series plot comparing actual demand against fitted values. The x-axis represents dates, while the y-axis shows the national demand. There is a clear seasonal pattern visible in the data, with peaks and troughs occurring at regular intervals. The model residuals are also shown, indicating the difference between the actual and fitted values. The residuals appear to be randomly distributed, suggesting that the model captures the seasonal effect well.
Including A Weather Effect
Actual Demand Vs Fitted Values

Date

Model Residual

National Demand at 2B

30,000

35,000

40,000

45,000

-8000

-4000

0

2000

6000
Including A School Holiday Effect
Actual Demand Vs Fitted Values
Time Series with Linear Regression
Trend Models

Yesterday

Today

1F 1A 04 1B

1F 1A 04 1B 2A 2B 3B 3C/DP 4B
Including A School Holiday Effect
Actual Demand Vs Fitted Values

Model Residual

Date
Including A Trend Component
Actual Demand Vs Fitted Values
The Model Symbolically

\[ L2B \sim L04 + DWK + SCH + EI + CP + \varepsilon \]

- Trend term
- Day of Week Effect
- Weather Effect
- Error term
Modelling CP Demand

- Construct forecast models using variables that make sense
- Use best model possible with variables that reduce the residual error significantly
- Track ‘Basic Demand’, non-model component of demand
Basic Demand

- Manually track and forecast basic element of demand
Profile Matching

- Check how well CP forecasts match historic days
Choosing Basics

- Forecast basic demand
- Aim is to reduce risk of error

2B model: Jan-Feb 2013
Embedded PV Generation
Embedded PV Generation
Embedded Generation

- ‘Invisible’, non-metered
- Connected directly into distribution networks
- Effectively reduces demand on the system
- Not just PV…
The Impact of Embedded Generation

- True GB Demand is higher than National Grid observe
- Not a new phenomenon, but an increase in more variable technologies means it is a more significant effect
  - Wind Power ~ 2,000 MW
  - Solar Power ~ 1,500 MW
Virtual Demand: A True National Demand

Embedded Generation

National Demand

Virtual Demand
Model Using Virtual Demand

- Virtual Demand
- Weather Component
- Week Day Component
- Basic Demand
Forecast Virtual Demand; Adjust for Embedded Generation

Weather Component
Week Day Component
Basic Demand
Embedded Generation

National Demand
The Forecasting Process

Model using Virtual Demand

- National Demand
- Embedded Generation
- Week Day Component
- Basic Demand
- Weather Component

Forecast Virtual Demand; Adjust for Embedded Generation

- National Demand
- Embedded Generation
- Basic Demand
- Week Day Component
- Weather Component
Forecasting Embedded Wind Generation
Existing Forecasting Methods

Wind Power Forecasting System
- Metered Wind ~ 5,800 MW
- Embedded ~ 2,000 MW

Metered Wind Farms

Embedd Wind Farms

Metered Wind Power Forecast

National Demand Forecast
Decile wind speed forecast applied to a load curve

Load curves for each wind generator, optimised using actual metering
Wind Power forecast probabilistic view for next 5 days from Mon 3rd Dec 2012

Wind Power Forecast - Probabilistic View for Next 5 Days

Wind Cut-out Forecast
Metered wind generation forecast

- Use same process to forecast embedded wind
- Have information on location and capacity for all embedded wind generators above 2MW
Forecasting Embedded Generation
Simulated National PV Output
Forecasting Embedded Generation
Forecasting PV

- National average radiation forecast
- Generic power curve
- National capacity
The challenges of PV

**Embedded Wind**
- Individual locations and capacities
- Wind speed forecasts for various locations
- Experience forecasting metered wind

**Embedded PV**
- Overall capacity for whole country
- National Average radiation
- No operational experience yet
Forecasting Embedded Generation
Forecasting PV

density.default(x = X3B_Basic + Output_1500, bw = 300)

density.default(x = X3C_Basic + Output_1700, bw = 300)
The Problem with Embedded Generation

- ~ 3,500 MW installed capacity
- Variable output dependant on weather effects
- Changing capacity levels
- Reliant on estimates of output
- No means of directly testing forecast models
- Increases the volatility of National Demand
Including A Trend Component
Actual Demand Vs Fitted Values
Including Embedded Wind Generation
Actual Demand Vs Fitted Values
Including Embedded Solar Generation
Actual Demand Vs Fitted Values

Model Residual
Thanks for listening
Demand and Wind Forecasting