IMAGES update

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June 28, 2017

Summary of past work (prior to leave)

Have developed a family of algorithms:

- An algorithm for maximising the arbitrage profit of a store. *Time horizons* - at each time t, need to know prices only up to a time $t + h_t$ in order to decide on the optimal action at time t. In this way, some price uncertainty is implicitly included, to an extent.
- Generalised to...algorithms which incorporate gas (for CAES), market impact of storage and various costs.
- A rolling horizon algorithm for incorporating a greater degree of price uncertainty.
- An algorithm to deal with competing stores.

Summary of past work (prior to leave)

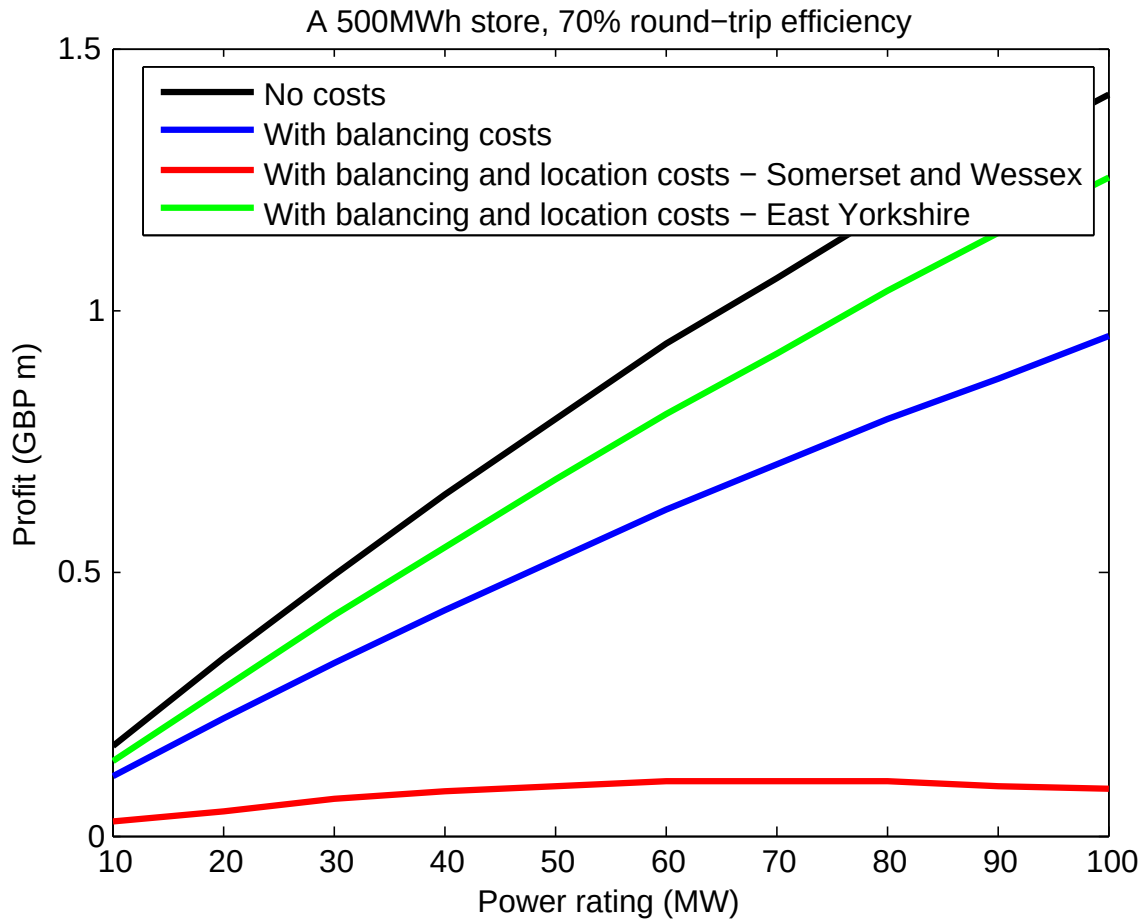
Also:

- Started to develop an algorithm for using a store to smooth the output of wind farms.
- Investigated the fees which a store must pay to National Grid, including the impact of location...lots of details available for anyone who is interested in this.

Summary of annual National Grid fees

- Transmission Network Use of System (TNUoS) charge: approx. proportional to installed output power capacity (but also includes an additional charge for demand over the Triad periods). Includes a locational element.
- Connection charge: proportional to initial cost of installing connection assets.
- Balancing Services Use of System (BSUoS) charge: approx. a half-hourly fee per MWh of energy delivered or used by the store).
- Lots of details available for anyone who is interested.

Insight into the impact of annual National Grid fees



- Elexon MID prices, 17.11.13-16.11.14, deterministic profit maximisation. Other fees to be paid in addition.
- (Please switch the labels for the green and the red!)

More recent work

- Have updated algorithms to include negative prices.
- Including price (or more generally cost) uncertainty. Two approaches: 1) rolling approach and 2) stochastic optimisation.
- Using a store for smoothing.

Including price uncertainty: a rolling approach

- Use a deterministic optimisation to decide on the action of the store at time 1 based on future price predictions available at that time...
- ... then, at time 2, update future price predictions and repeat the above to decide on action at time 2...
- A relatively simple method (we can already implement this) which can be easily extended to included other factors such as balancing markets (e.g. the Capacity Market).
- Practical for real-time operation: real-time decisions are made quickly (typically $<$1s) and no end-time or end-condition is needed.
- The quality of the output depends on making good predictions over the required time horizons.

Including price uncertainty: a stochastic optimisation

- Instead of future price predictions, input a probability distribution for future prices.
- How to operate the store in order to maximise expected profit?
- Have extended our previous theory to this setting.
- Have an initial prototype for an algorithm, but still developing this in order to reduce number of computations.
- There are existing methods for this, but they tend to either be too computationally heavy, or they rely on making initial approximating assumptions. Generally very easy to make bad initial approximations $\rightarrow$ poor quality solution. Not an issue with our method.

Using a store for smoothing

- Continuing previous work to include power constraints.
- Using a store to smooth wind output is probably a social welfare problem - is there any benefit to the store?
- Doesn't have to be wind - could be, for instance, the amount of non-renewable generation required to meet demand.
- Precisely, given wind energy outputs $w_1, \ldots, w_T$ up to time T, choose the energy outputs $x_1, \ldots, x_T$ of a store to minimise the total variation:

$$\sum_{t=1}^{T-1} |(x_{t+1} - w_{t+1}) - (x_t - w_t)|. \qquad (1)$$

- The same property occurs as before - we only need to predict wind (say) up to a time $t + h_t$ in order to decide what to do at time t.

Summary

- Algorithms have previously been developed for the profit maximisation of a store, in a number of different settings. These all include, to some extent, price uncertainty.
- A rolling approach could be easily implemented to include price uncertainty (to a greater extent) and other factors, e.g. balancing markets.
- Good for simplicitly and adaptability, and useful if probability distributions are not easy to estimate.
- A new stochastic optimisation approach, which allows for probability distribution inputs, is being developed.
- National Grid fees, which depend in part on the location of the store, could potentially have a significant impact.