Trading wind energy based on probabilistic forecasts of wind generation and market quantities

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What is the article about ?

Context

- Portfolio of wind energy (can be solar)
- Liberalized electricity markets

Goals

- Propose an operational trading strategy (*based on the quantile of wind power production*)
- Assess its performance

Inputs of the model

Forecasts of

- Wind power production
- Spot market prices
- Imbalance prices (*regulating market prices*)

Remark : Not a forecasting problem !

What are the main assumptions ?

Assumptions

- Price-taker
- No practical limitations
- Don't care about the risk : only the long run matters , ie we may face severe losses on the short run
- No curtailment
- PTU (*Program Time Units*) are independent : no market dynamic.
- Imbalance volumes are never rewarded

Notations

Notations

- k : a specific PTU
- $\widetilde{W}_k$: amount of energy contracted in the spot market
- W_k : stochastic production of wind energy
- ρ_k : revenue
- $\rho_k^{(S)}$: revenue from spot
- $\rho_k^{(\uparrow/\downarrow)}$: revenue from balancing
- $\pi_k^{(S)}$: spot market price
- $\pi_k^{(\downarrow)}$: down-regulation price
- $\pi_k^{(\uparrow)}$: up-regulation price

Some relations

Relations that hold

- $\rho_k = \rho_k^{(S)} + \rho_k^{(\uparrow/\downarrow)}$
- $\rho_k^{(S)} = \pi_k^{(S)} \widetilde{W}_k$
- $\rho_k^{(\uparrow/\downarrow)} = \begin{cases} \pi_k^{(\downarrow)} \left(W_k - \widetilde{W}_k \right), & W_k \geq \widetilde{W}_k \\ \pi_k^{(\uparrow)} \left(W_k - \widetilde{W}_k \right), & W_k < \widetilde{W}_k \end{cases}$
- $\pi_k^{(\downarrow)} \leq \pi_k^{(S)} \leq \pi_k^{(\uparrow)}$

Reformulating the revenue

Reformulating the revenue

- $\rho_k = \pi_k^{(S)} W_k + C_k^{(\uparrow/\downarrow)}$
- $C_k^{(\uparrow/\downarrow)} = \begin{cases} \psi_k^{(\downarrow)} \left(W_k - \widetilde{W}_k \right), & W_k \geq \widetilde{W}_k \\ \psi_k^{(\uparrow)} \left(W_k - \widetilde{W}_k \right), & W_k < \widetilde{W}_k \end{cases}$
- $\psi_k^{(\downarrow)} = \pi_k^{(\downarrow)} - \pi_k^{(S)}$
- $\psi_k^{(\uparrow)} = \pi_k^{(\uparrow)} - \pi_k^{(S)}$

Idea

- revenue $= \left(\text{term ind. from } \widetilde{W}_k \right) + (\Delta\text{price } \cdot \Delta\text{imb. volumes})$

Expected Utility Maximization (EUM)

- We want to find $\widetilde{W}_k = \underset{\widetilde{W}_k}{\arg\max} \mathbb{E}\left\{\rho_k\right\}$
- ... which becomes $\widetilde{W}_k = \underset{\overline{W}_k}{\arg\max} \mathbb{E}\left\{C_k^{(\uparrow/\downarrow)}\right\}$

Reformulating $C_k^{(\uparrow/\downarrow)}$

- $$\mathbb{E}\left\{C_k^{(\downarrow/\uparrow)}\right\} = \underbrace{\int_0^{+\infty}\int_0^{\widetilde{W}_k} \psi_k^{(\uparrow)}\left(W_k - \widetilde{W}_k\right) dP_{W_k} dP_{\psi_k^{(\uparrow)}}}_{\widetilde{W}_k \geq W_k:\ \text{short position}}$$
$$+ \underbrace{\int_{-\infty}^{0}\int_{\widetilde{W}_k}^{W^{(max)}} \psi_k^{(\downarrow)}\left(W_k - \widetilde{W}_k\right) dP_{W_k} dP_{\psi_k^{(1)}}}_{\widetilde{W}_k < W_k:\ \text{long position}}$$

A stochastic optimization problem

A stochastic optimization problem

- Idea: getting rid of $\psi_k^{(\downarrow)}$ and $\psi_k^{(\uparrow)}$
- $\mathbb{E}\left\{C_k^{(\downarrow/\uparrow)}\right\} = \widehat{\psi}_k^{(\uparrow)} \int_0^{W_k} \left(W_k - \widetilde{W}_k\right) dP_{W_k}$
  $+\widehat{\psi}_k^{(\downarrow)} \int_{\widetilde{W}_k}^{W^{(max)}} \left(W_k - \widetilde{W}_k\right) dP_{W_k}$
- ... where $\widehat{\psi}_k^{(\uparrow)} = \int_0^{+\infty} \psi_k^{(\uparrow)} dP_{\psi_k^{(\uparrow)}}$
- ... and $\widehat{\psi}_k^{(\downarrow)} = \int_{-\infty}^{0} \psi_k^{(\downarrow)} dP_{\psi_k^{(\downarrow)}}$

Remark

- Are $\left\{ \psi_{k,t}^{(\downarrow)} \right\}_t$ and $\left\{ \psi_{k,t}^{(\uparrow)} \right\}_t$ stationary ?

Solution of the SOP

Solution

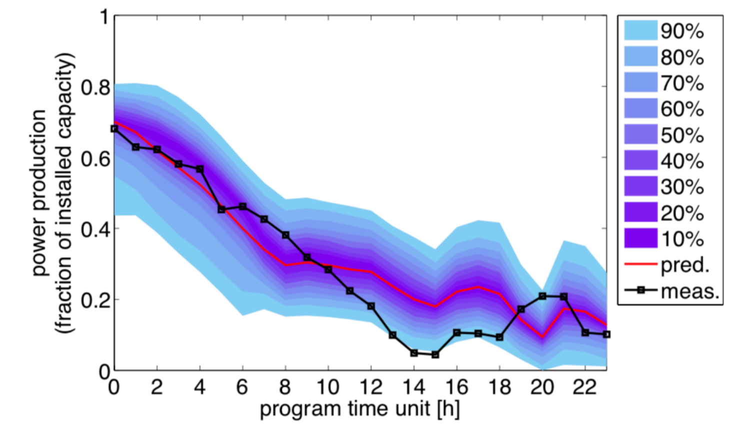
- $\widetilde{W}_k = F_{W_k}^{-1}\left(\frac{\left|\widehat{\psi}_k^{(\downarrow)}\right|}{\widehat{\psi}_k^{(\uparrow)}+\left|\widehat{\psi}_k^{(\downarrow)}\right|}\right)$
- F_{W_k} cumulative distribution function of W_k.

Remark

- A probabilistic forecast of W_k is needed

Probabilistic forecast of W_k

Probabilistic forecast of production for a wind power portfolio in Eastern Denmark provided at 11 AM.



How to compute unknown values ?

Estimators of unknown values

- spot price: $\widehat{\pi}_k^{(S)} = \mathbb{E}\left\{\pi_k^{(S)}\right\}$
- spread between spot and imbalance prices :
  - Down : $\widehat{\psi}^{(\downarrow)}_{k\left|\psi_k^{(\downarrow)}<0\right.} = \mathbb{E}\left\{\psi_k^{(\downarrow)}|\psi_k^{(\downarrow)} < 0\right\}$
  - Up : $\widehat{\psi}^{(\uparrow)}_{k\left|\psi_k^{(\uparrow)}>0\right.} = \mathbb{E}\left\{\psi_k^{(\uparrow)}|\psi_k^{(\uparrow)} > 0\right\}$

Remark

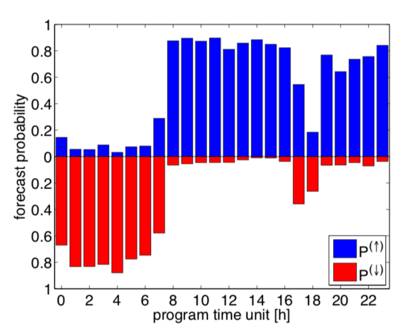
- $P_k^{(\downarrow)} = P\left\{\psi_k^{(\downarrow)} < 0\right\}$ and $P_k^{(\uparrow)} = P\left\{\psi_k^{(\uparrow)} > 0\right\}$ need to be computed
- ... since $\widehat{\psi}_k^{(\downarrow)} \neq \widehat{\psi}^{(\downarrow)}_{k\left|\psi_k^{(\downarrow)}<0\right.}$ but $\widehat{\psi}_k^{(\downarrow)} = \widehat{\psi}^{(\downarrow)}_{k\left|\psi_k^{(\downarrow)}<0\right.} \cdot P_k^{(\downarrow)}$
- ... same for $\widehat{\psi}_k^{(\uparrow)}$ ...

How to compute unknown values ?

Estimators of $P_k^{(\downarrow)}$ and $P_k^{(\uparrow)}$

- $P_k^{(\downarrow)} = P\left\{\psi_k^{(\downarrow)} < 0\right\}$
- $P_k^{(\uparrow)} = P\left\{\psi_k^{(\uparrow)} > 0\right\}$

Example of forecast probabilities of up and down



Conclusion

A successful strategy ?

- Simulation results show a PNL of $1OO$K euros /MW from the 1st March 2008 to the 31st December 2008.
- not modeling its interaction with the system. An aggresive position can make the system switch ...
- Model improvements ?
    - Imposing new constraints through a *risk-aversion parameter*...
    - $\widetilde{W}_k^{v,a_v} = \min\left\{\max\left\{\widetilde{W}_k, \widehat{W}_k \cdot (1-a_v)\right\}, \widehat{W}_k \cdot (1+a_v)\right\}$
    - ... where $a_v \in \{0.1, 0.2\}$