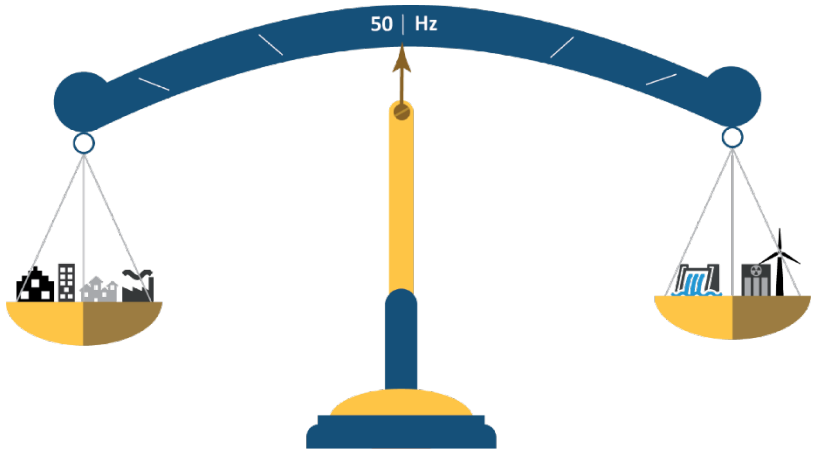
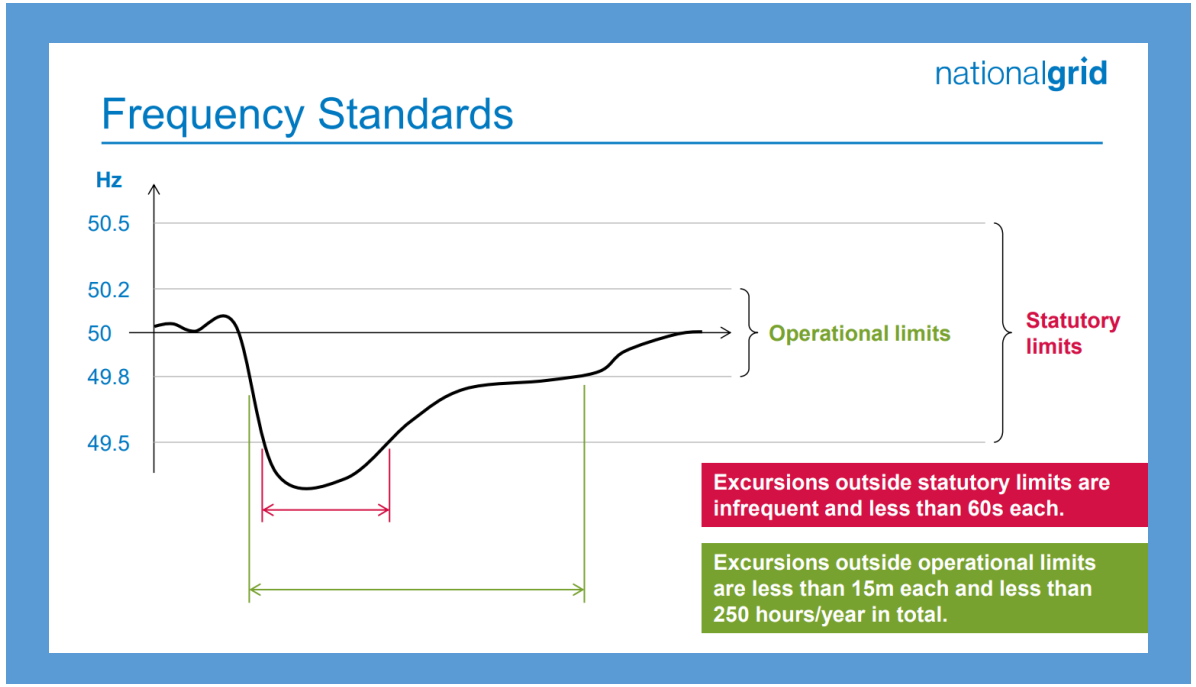
Forecasting Wind Power As A Dispatchable Generation Source for Grid Frequency Control

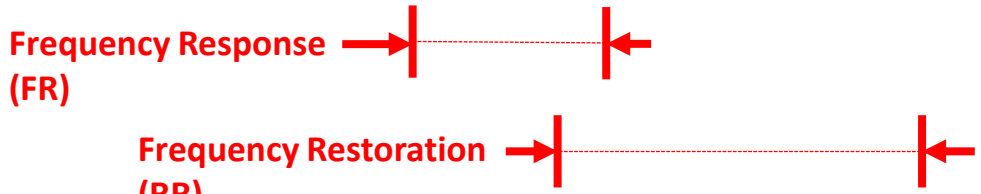
Leo May – University of Strathclyde

EPSRC Pioneering research and skills
Wind & Marine Energy Systems CDT
SCOTTISHPOWER RENEWABLES

Grid Frequency Control





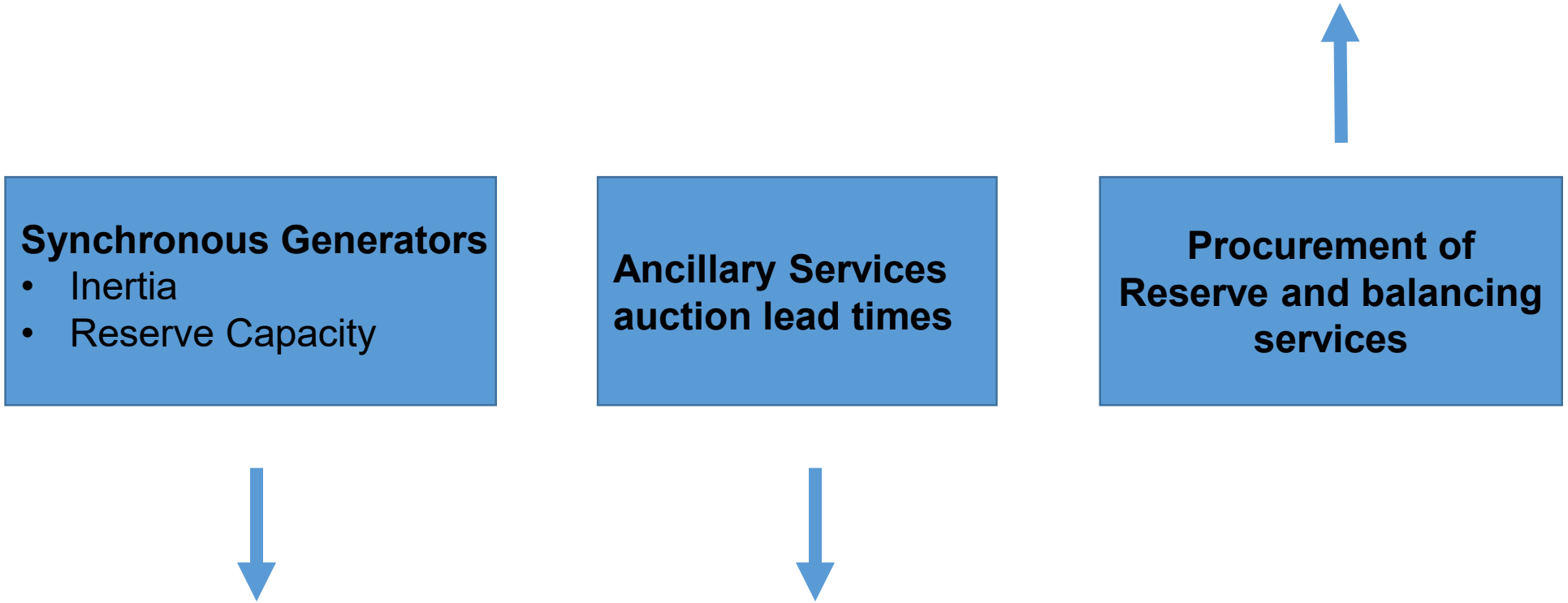


Sources:

https://www.nationalgrideso.com/sites/eso/files/documents/Faster%20Acting%20Response%20Workshop%20%282018-07%29.pdf

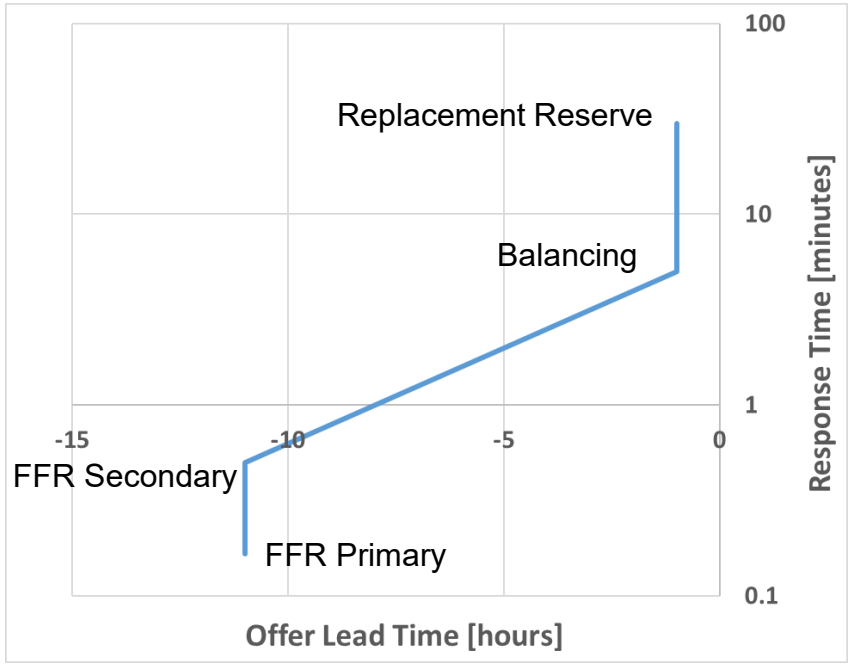
https://www.sintef.no/en/projects/pribas-pricing-balancing-services-in-the-future-no/

Decarbonisation



Time Horizon Value

- Assuming electricity markets are discovering value; fast response times are more valuable at longer lead times, especially in weaker grids.
- Due to ramping speeds, the auction for products with slow response times is more saturated.



Future of Offshore Wind

Strengths:

- High capacity share
- Operational Flexibility
- Low LCOE (right now)

Weaknesses:

- ‘Infirm’ capacity
- Subsidy based operation

Opportunities:

- Ancillary services
- Floating wind geographical flexibility
- Interconnector integration

Threats:

- Low wholesale energy price on windy days
- Slow policy reforms denying market access.

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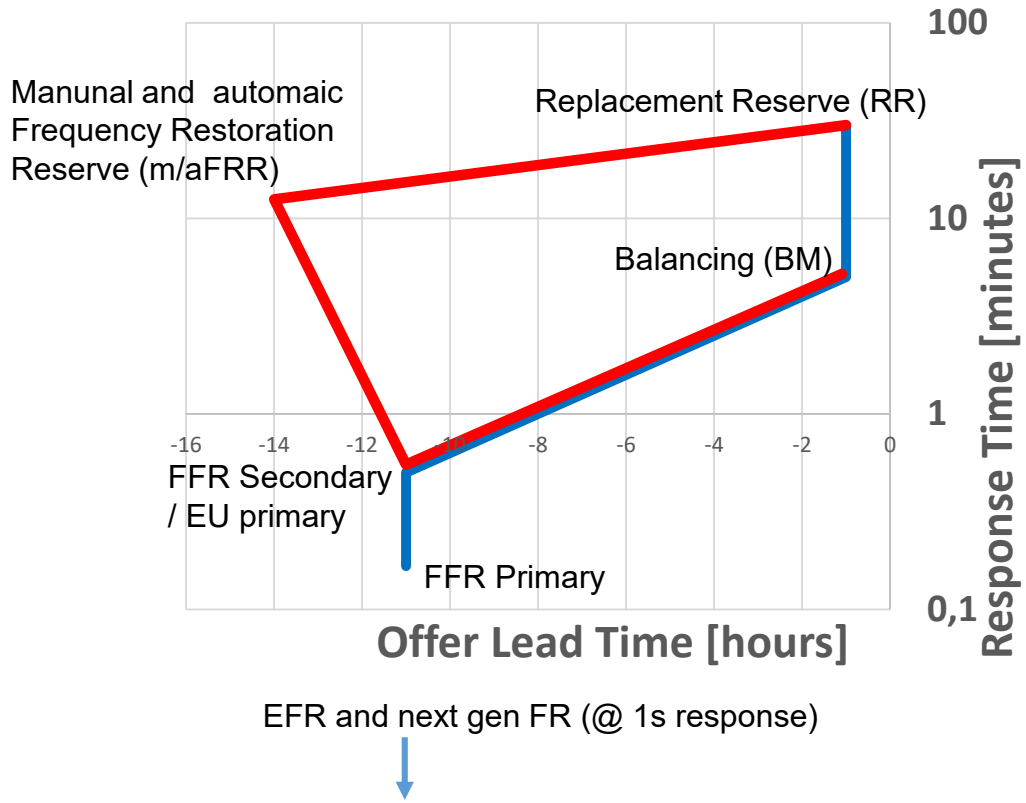

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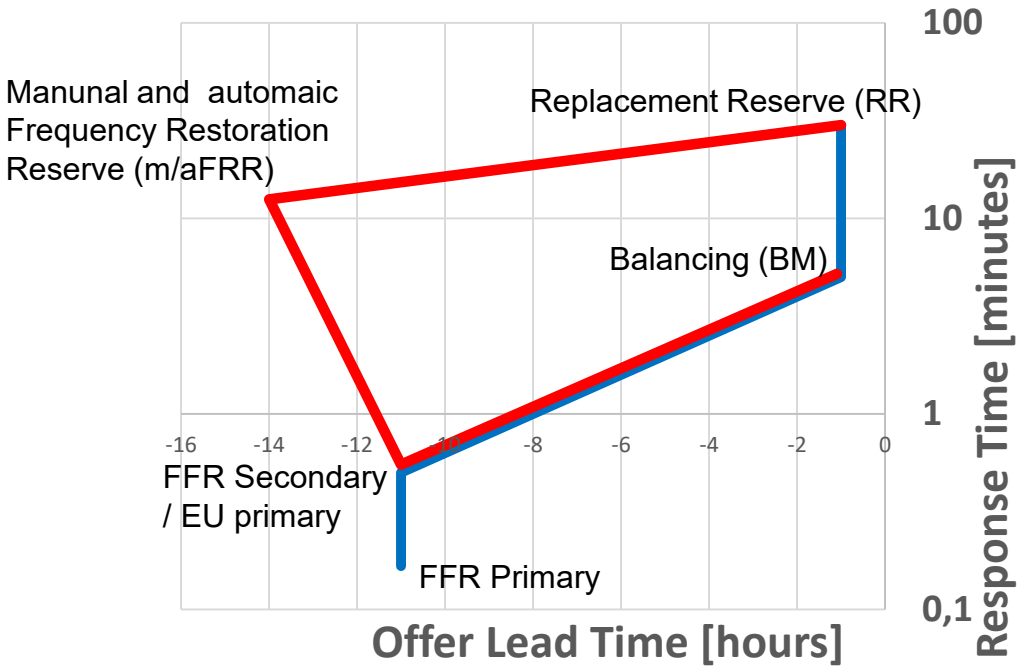
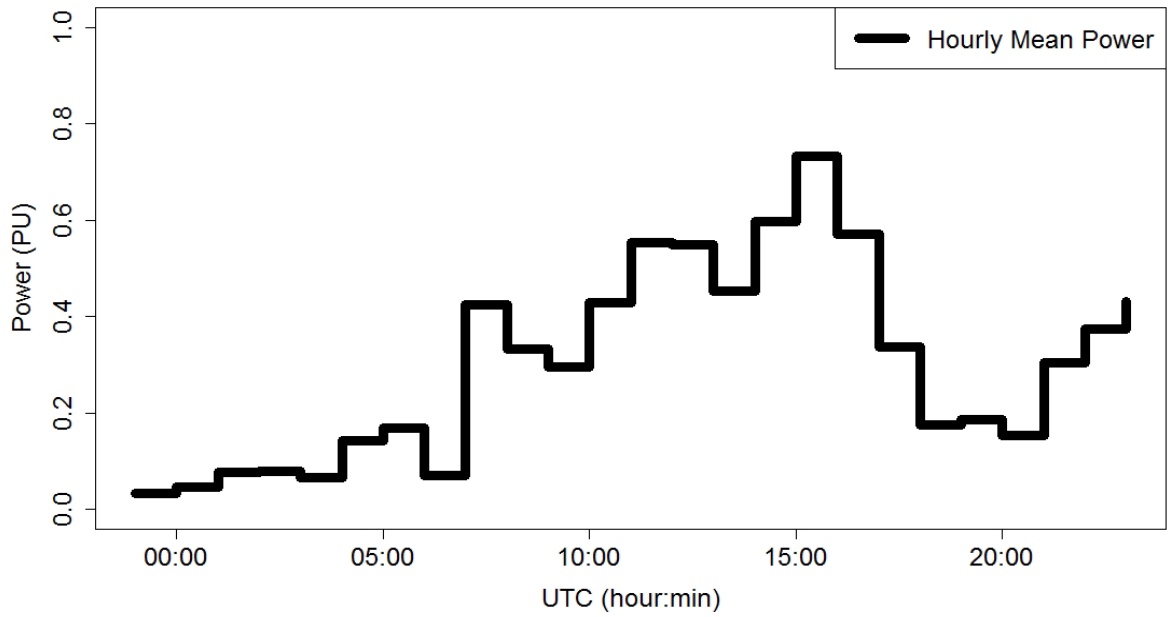


EFR and next gen FR (@ 1s response)

Near to mid term value for wind power plants

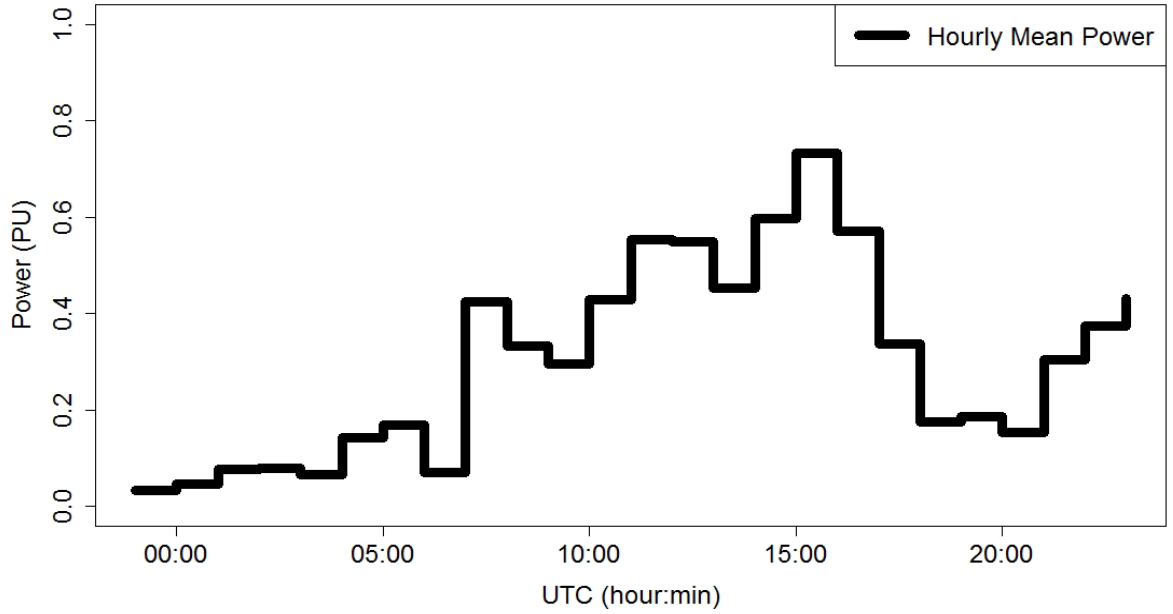
Wind Power Trading

- Electricity Forward Agreement (EFA) day is 11pm to 11pm
- Energy contracts in Megawatt Hours (MWH)
- Contracts traded for EFA blocks of 4 hours or individual hours.
- Day Ahead, Intraday and Balancing Markets.



Wind Power Trading

- Price per MWH reflects uncertainty in generation and demand up until gate closure (T-1 hours), balancing market mops up the remaining uncertainty and distributes fines to recoup running costs
- Balancing mechanism **dispatches in power** (MW) but **remunerates in energy** (MWH).



Wind Power Trading

- Energy [MWh]
- Power [MW]

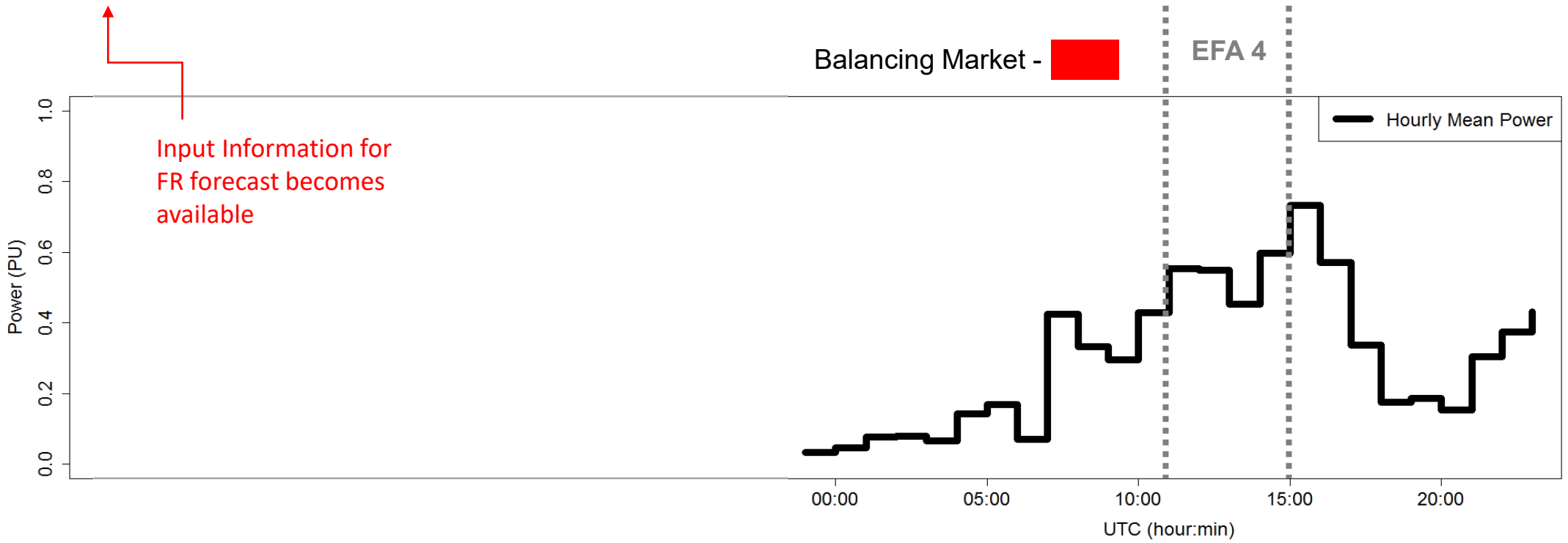
- Intraday Market

- Day Ahead Market

T-1 gate closure

Input Information for FR forecast becomes available

Balancing Market -



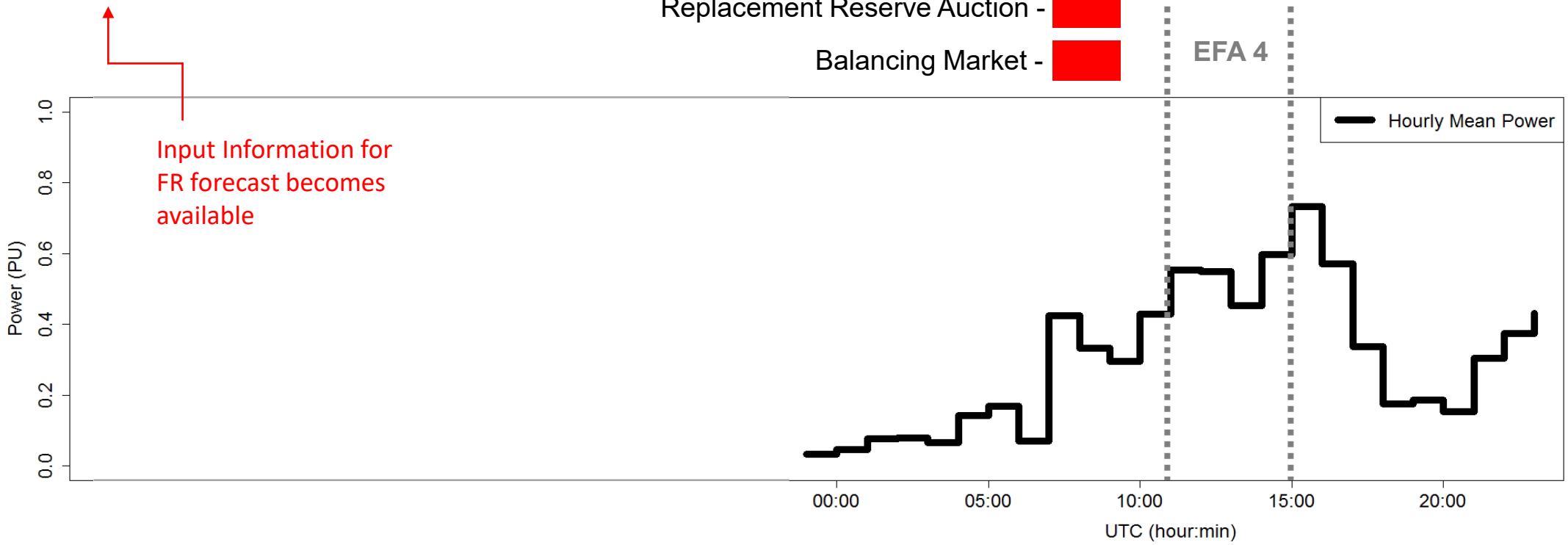
Wind Power Trading

- Energy [MWh]
- Power [MW]

- Intraday Market
- Day Ahead Market
- Frequency Response Auction
- Frequency Restoration Auction (aFRR & mFRR)
- Replacement Reserve Auction -
- Balancing Market -

T-1 gate closure

Input Information for FR forecast becomes available



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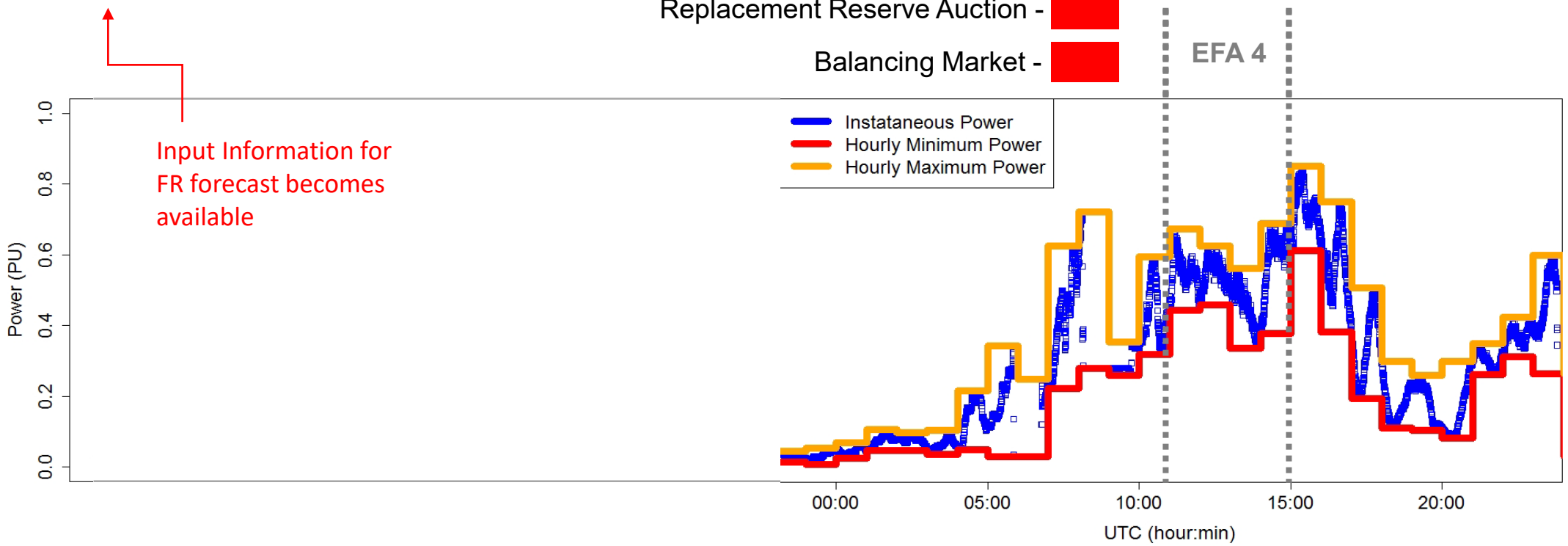

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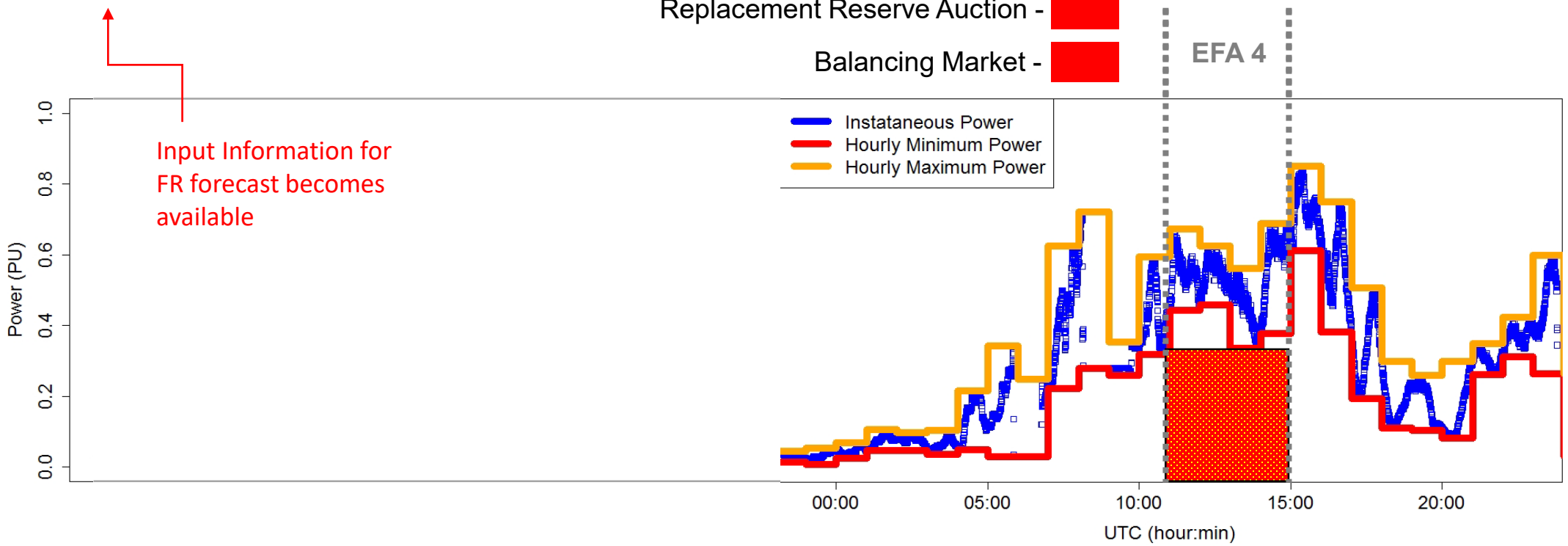

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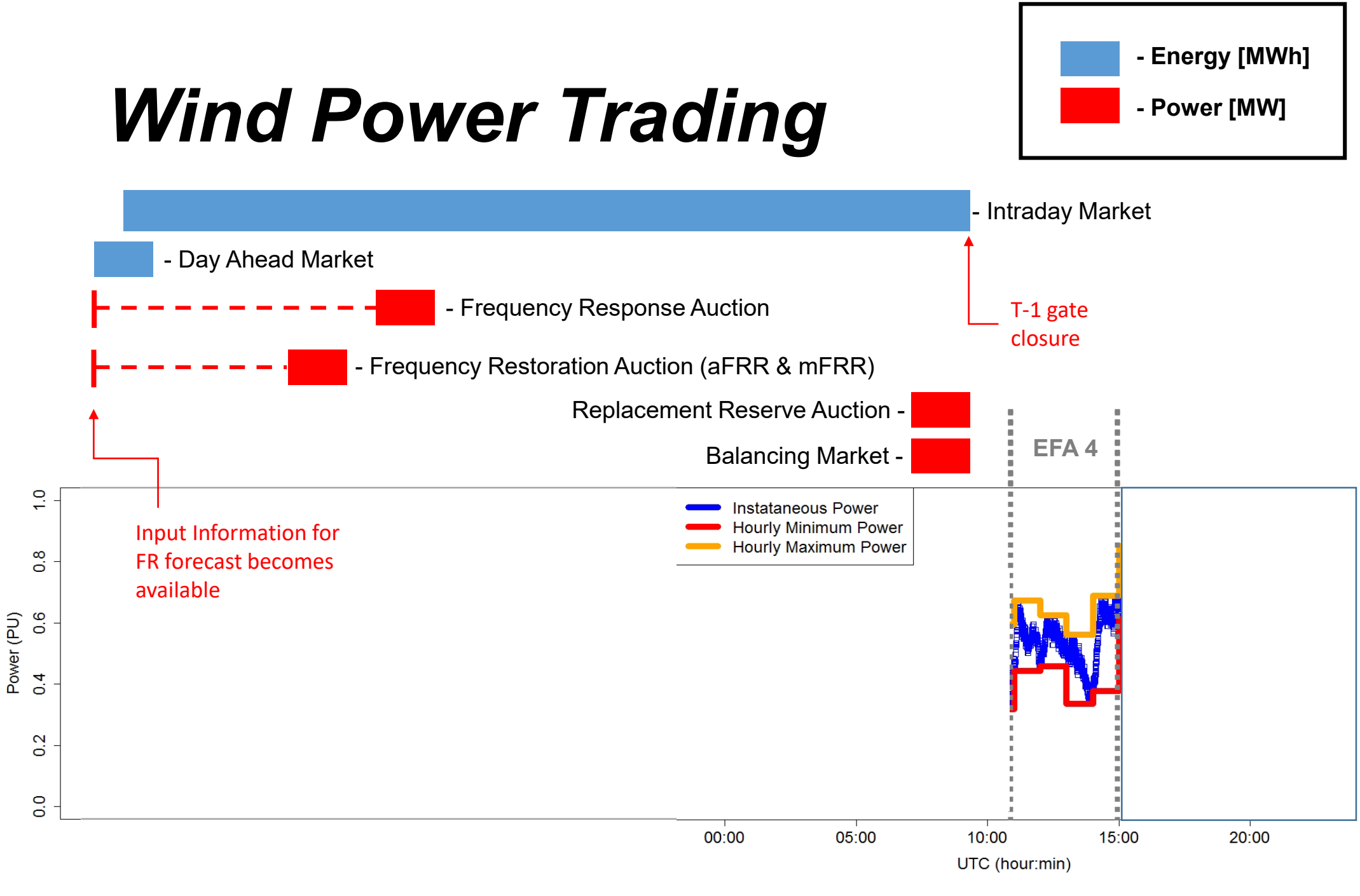

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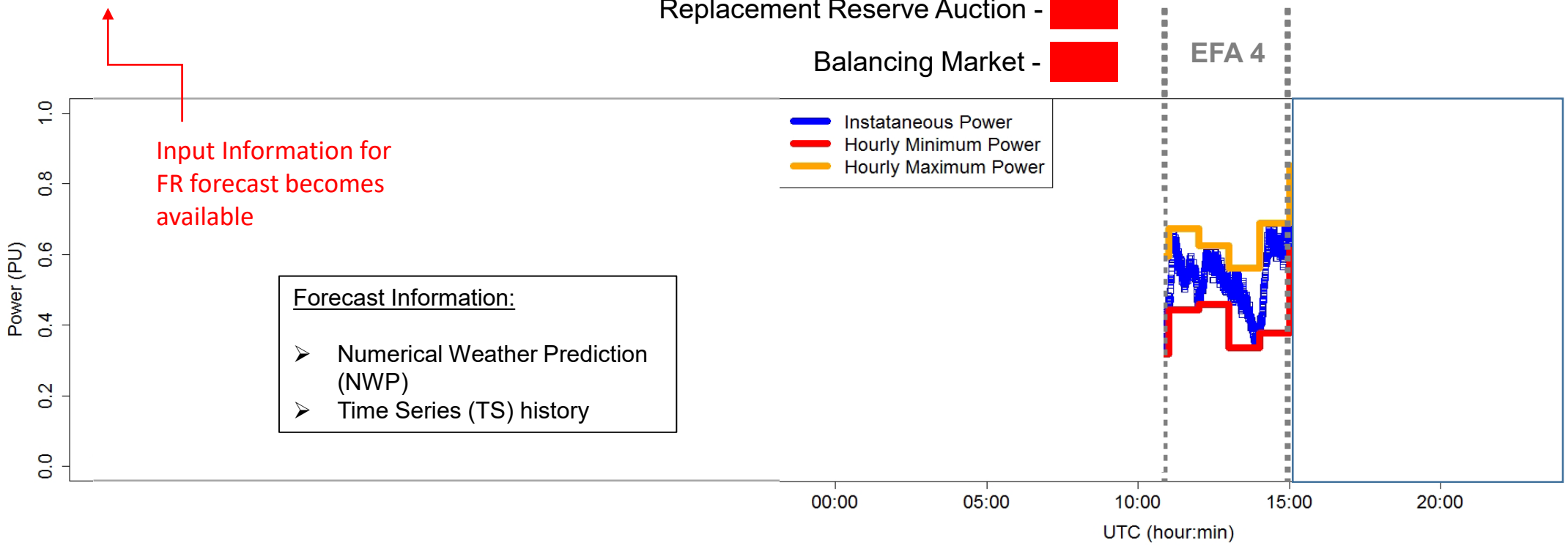
T-1 gate closure

Input Information for FR forecast becomes available

Forecast Information:

- Numerical Weather Prediction (NWP)
- Time Series (TS) history



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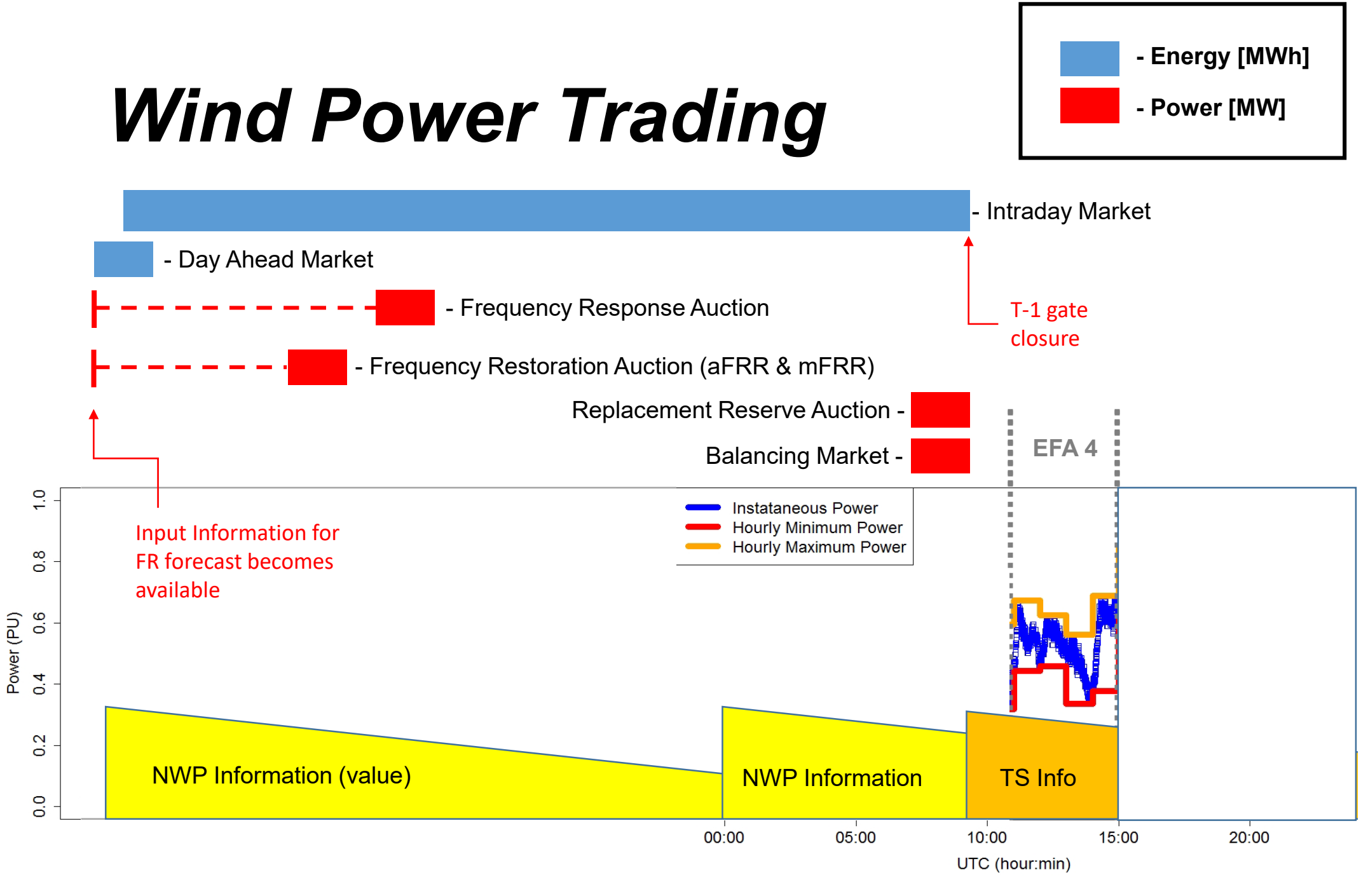

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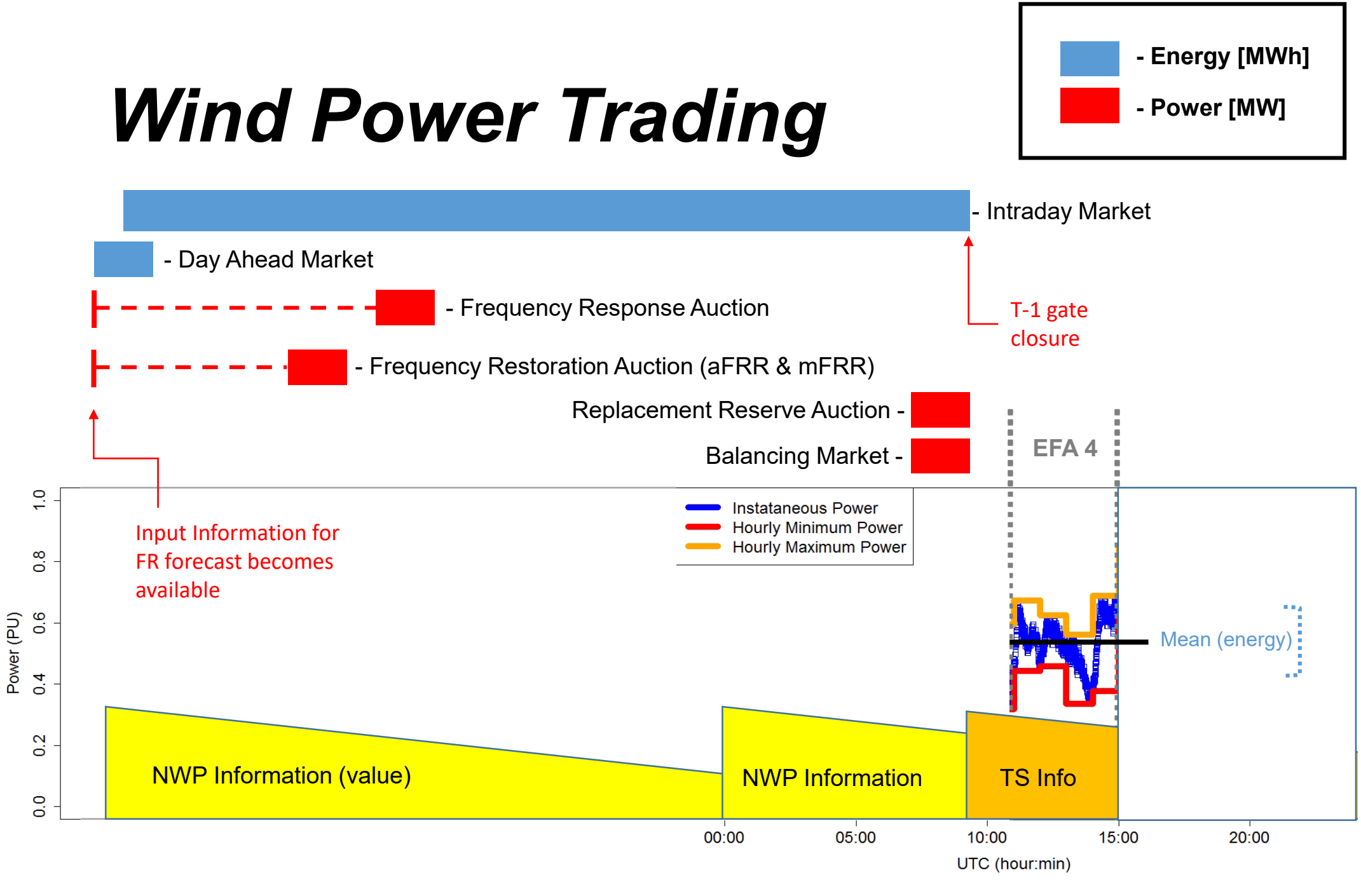

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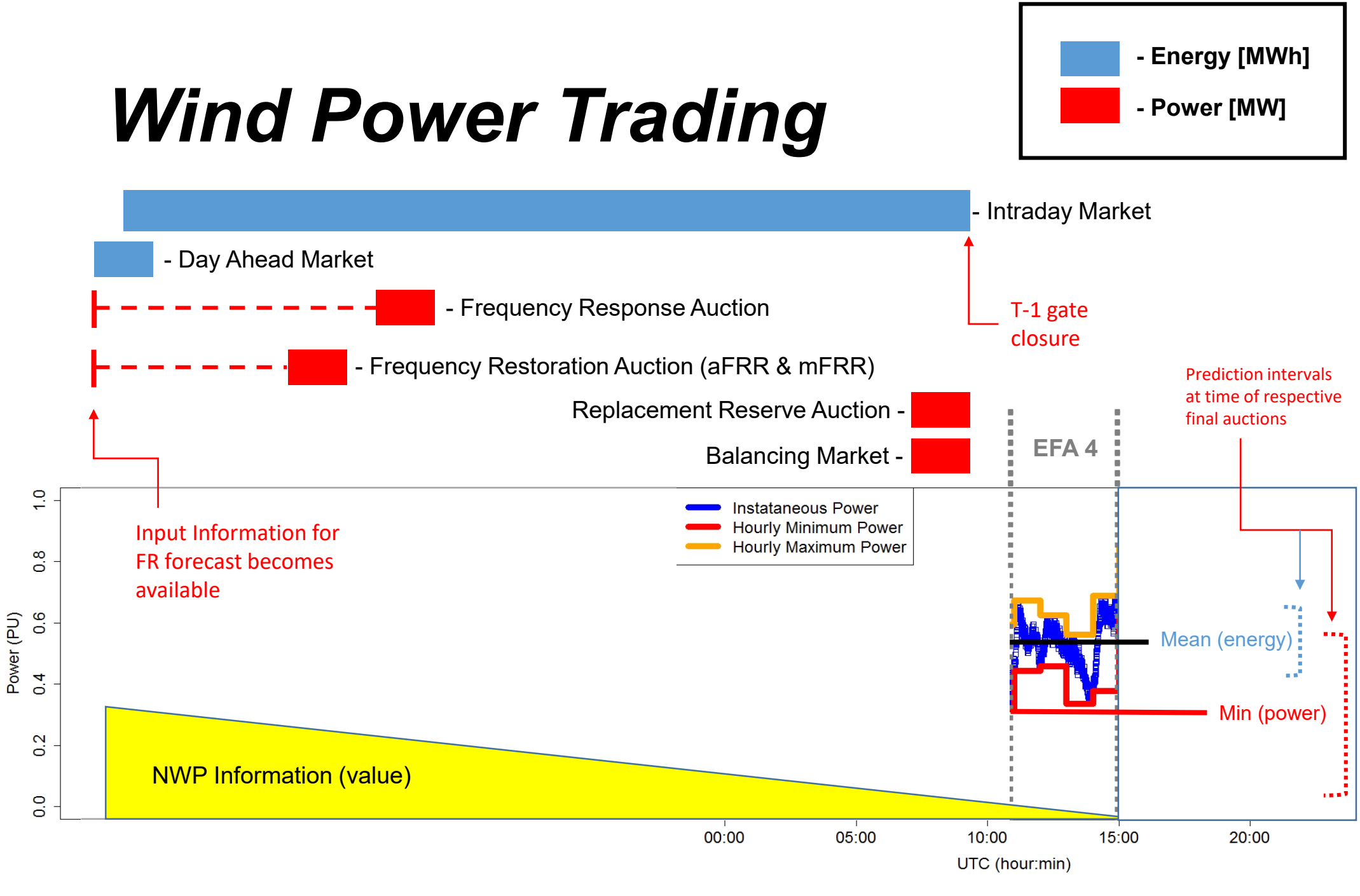

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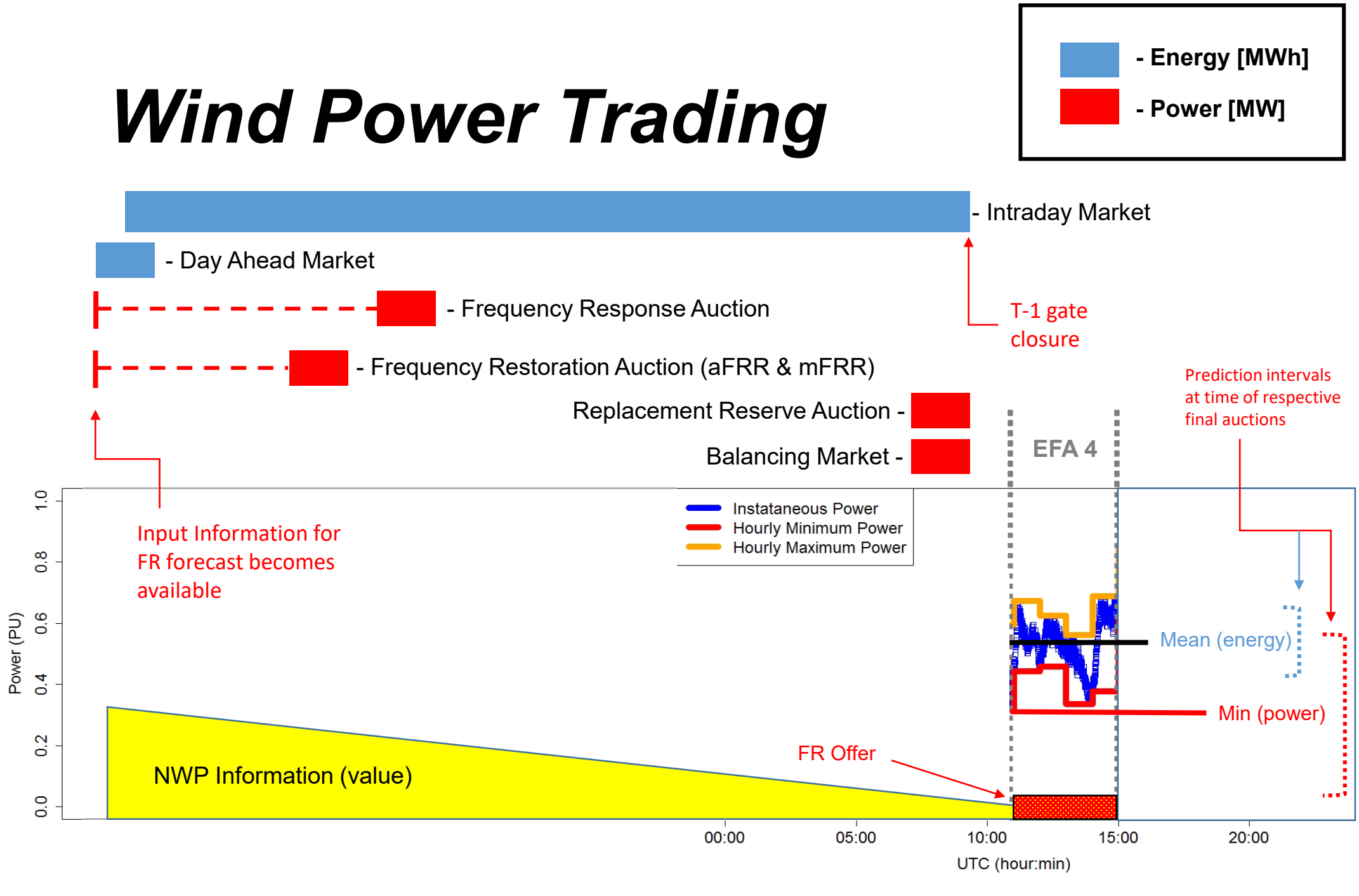

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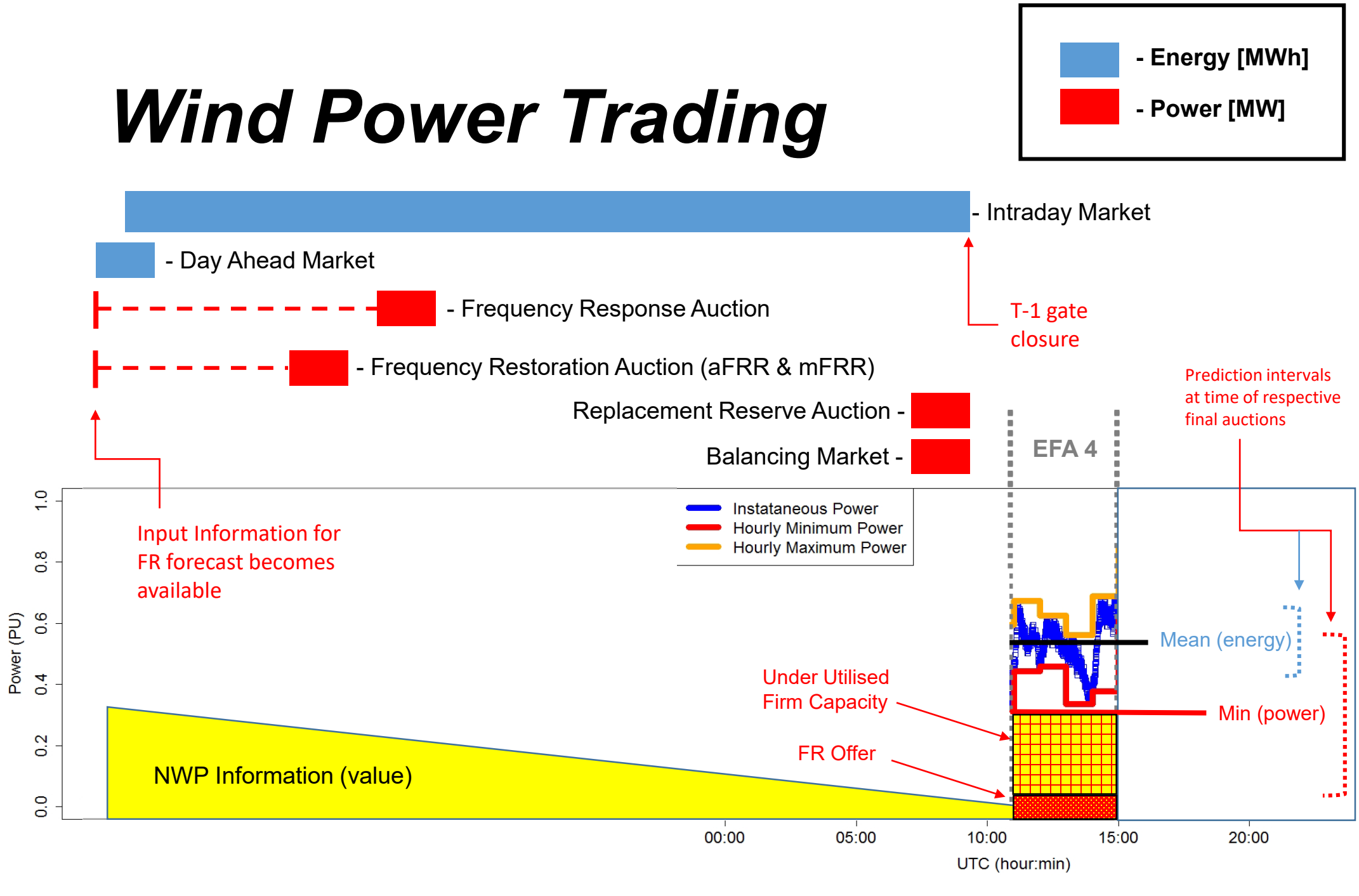

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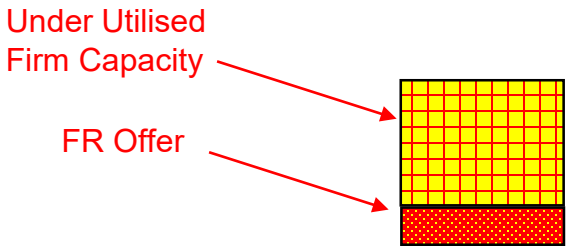

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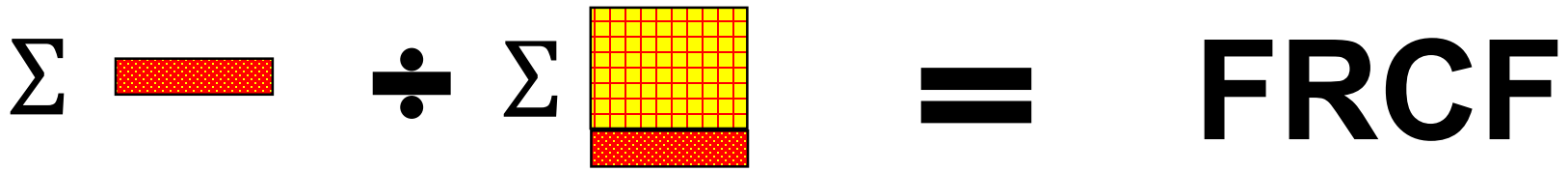
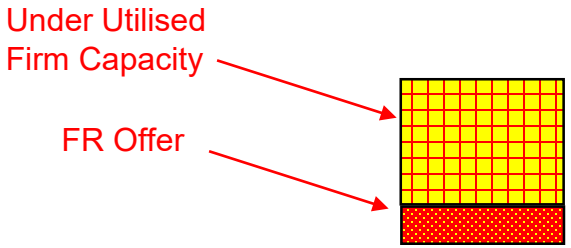
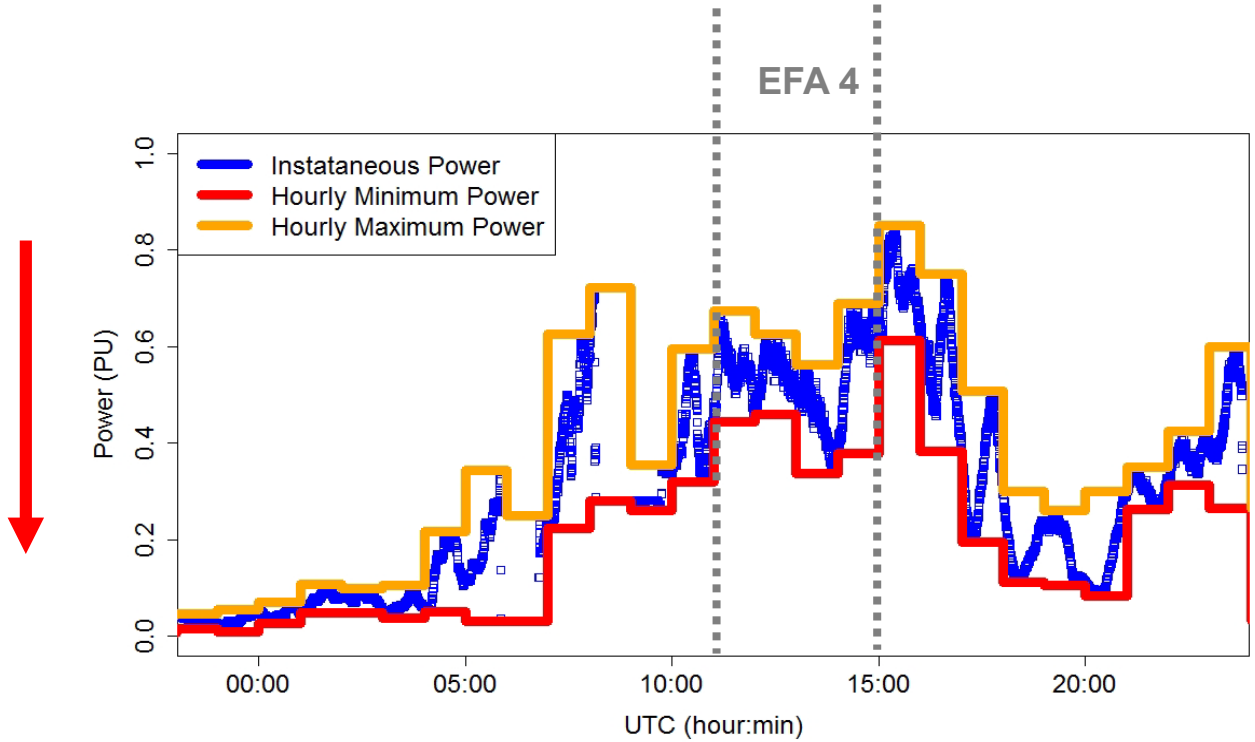


Sum of FR offer volumes divided by sum of hourly minimum powers = Frequency Response Capacity Factor



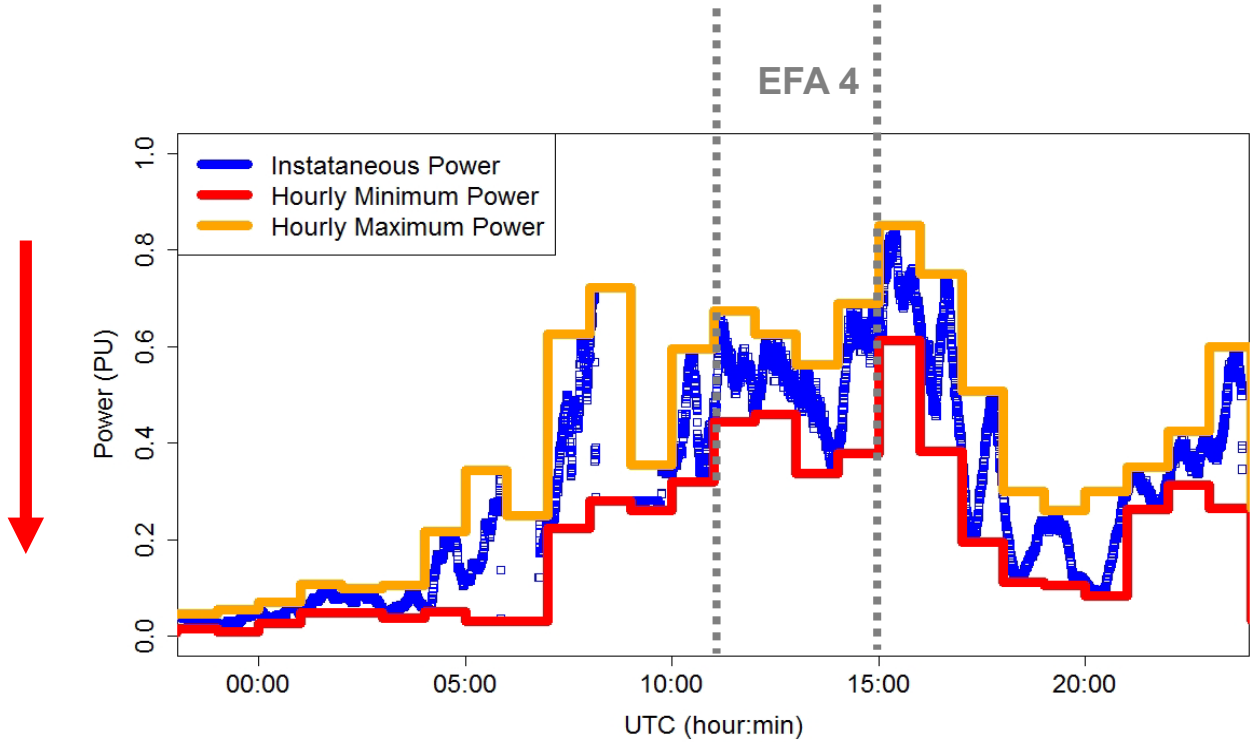
Firm Frequency Response – high

- Respond by lowering power output
- Full response within 10 seconds
- Triggered automatically at grid frequency threshold
- Sustain response until end of contract period.
- Proxy for all FR service capability.



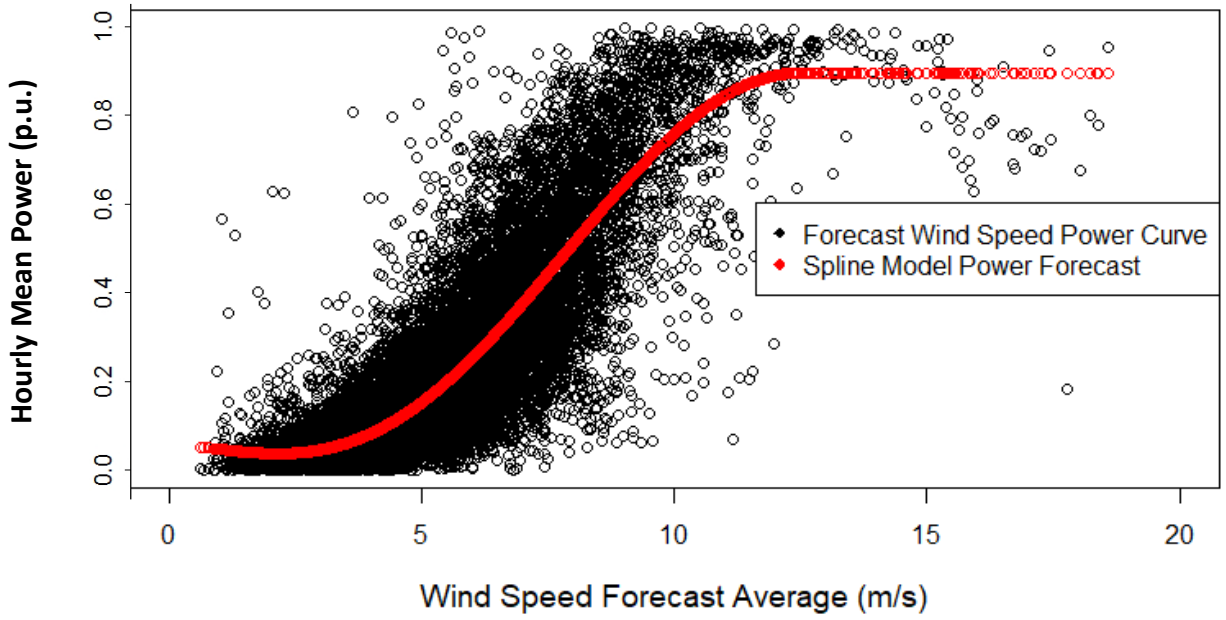
Forecasting Task Parameters

- Forecast hourly minimum power output of wind farm
- Use 24-48 horizon wind speed forecasts as input
- Quantify reliability / accuracy
- Seek to maximise forecast sharpness subject to reliability.



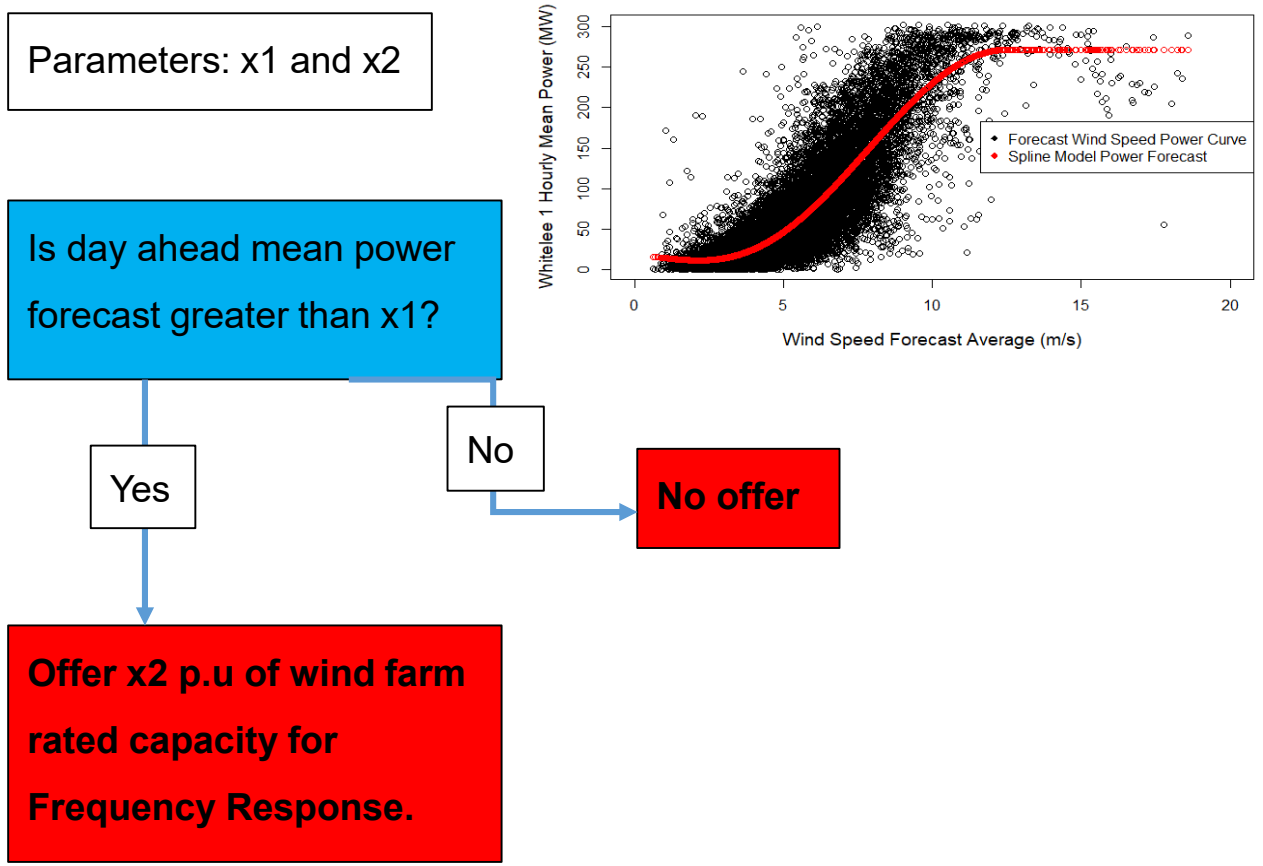
Benchmark – Day Ahead Energy

- Standard day ahead forecast method in wind energy trading
- Spline point forecast.
- Spline fitted with parameter grid search and k fold cross validation.
- Spline fitting implemented in R



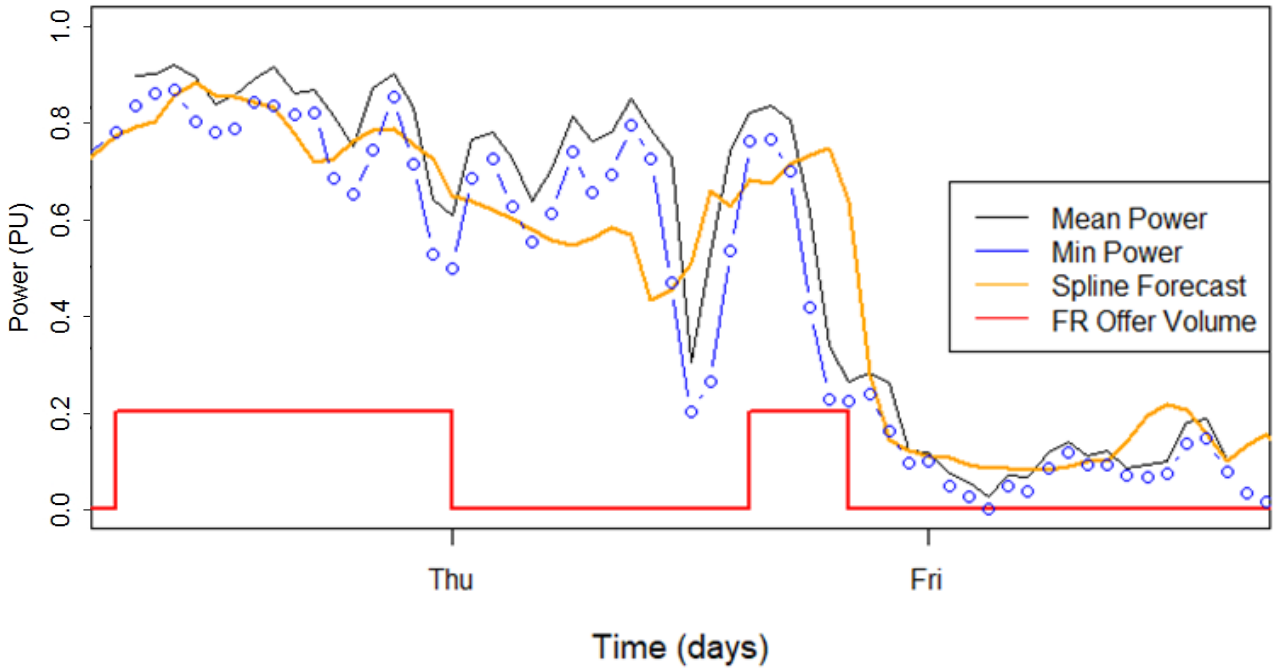
Benchmark – FR Offer Algorithm

- Spline forecast of mean – equivalent to calibrated power curve; the industry standard for day ahead forecasting.
- Estimate of minimum power derived from risk based algorithm applied to mean power forecast.
- Algorithm based on time invariant estimate of 1) day ahead energy forecast error and 2) hourly power variance



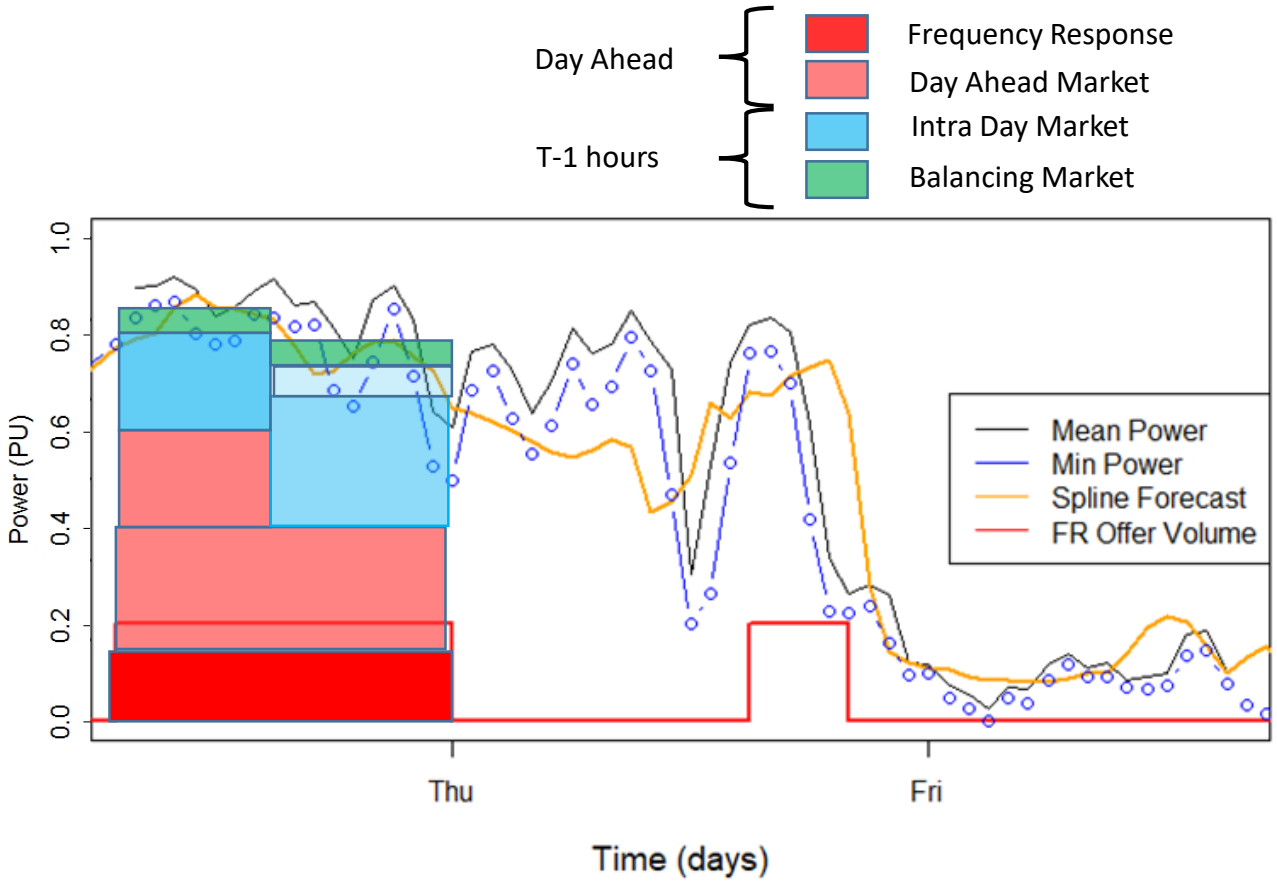
Benchmark - Example

- Hourly mean and minimum power with day ahead spline forecast of mean power
- **x1 = 0.66**
- **x2 = 0.2**
- Red line shows result of algorithm



Benchmark – Offer Strategies

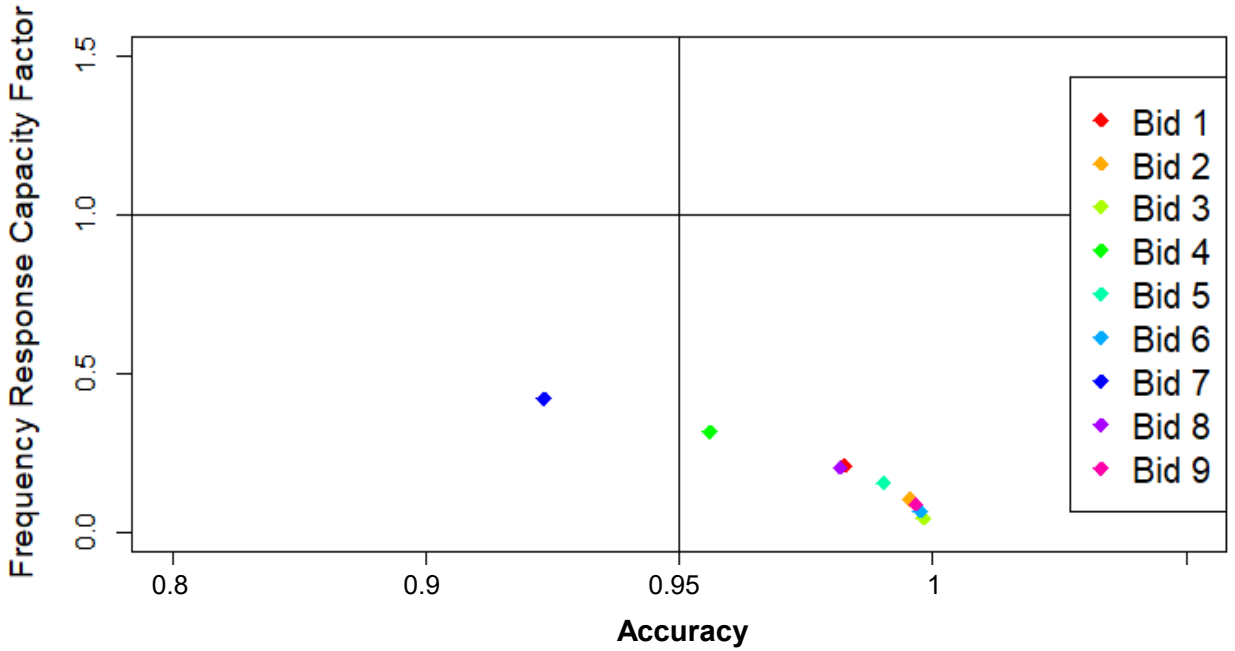
- Potential assignments for wind power at 24 hours ahead:
  - Day Ahead wholesale energy
  - Frequency Restoration Reserve
  - Frequency Response
- Leave for later:
  - Intra Day
  - Balancing Market
  - Restoration Reserve



Constraints: forecast uncertainty, forecast imbalance price, forecast day ahead price, frequency service auction strike prices.

Benchmark - Optimization

- Grid search of parameter combinations
- Goal is FRCF of 1 and accuracy of 95%
- 2 objectives simplified to Euclidian distance where x y scale of graph is definable to specify accuracy importance.



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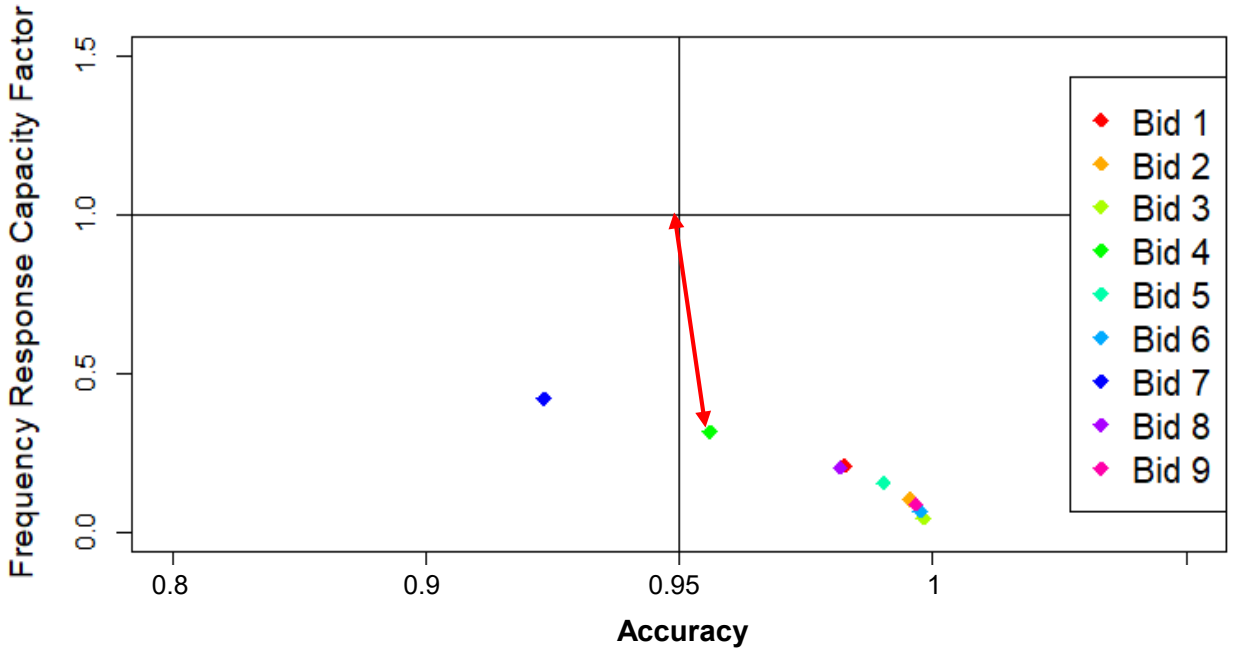
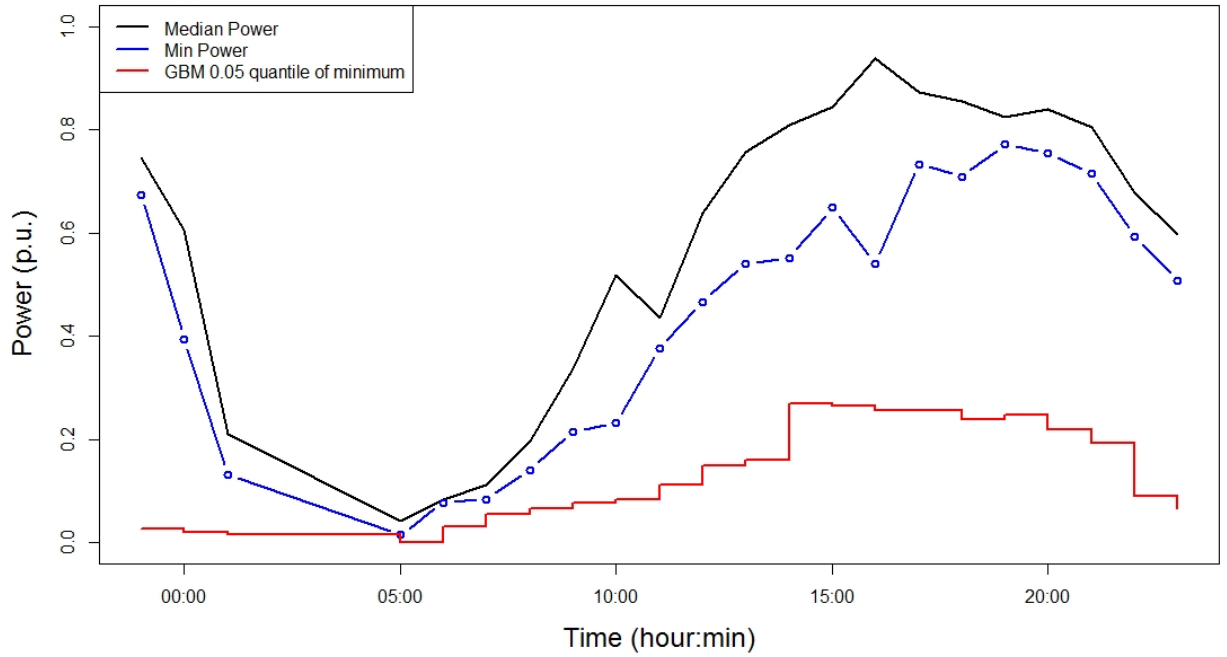


Quantile Forecast of Minimum Power

- Implementation of an explicitly probabilistic forecast approach.
- The 0.05 quantile forecast exceeds the target variable in 5% of instances.
- Quantile regression involves minimizing an asymmetrical loss function using weighting of inputs
- Reliable 0.05 quantile of minimum power would constitute a 95% reliable frequency response offer.



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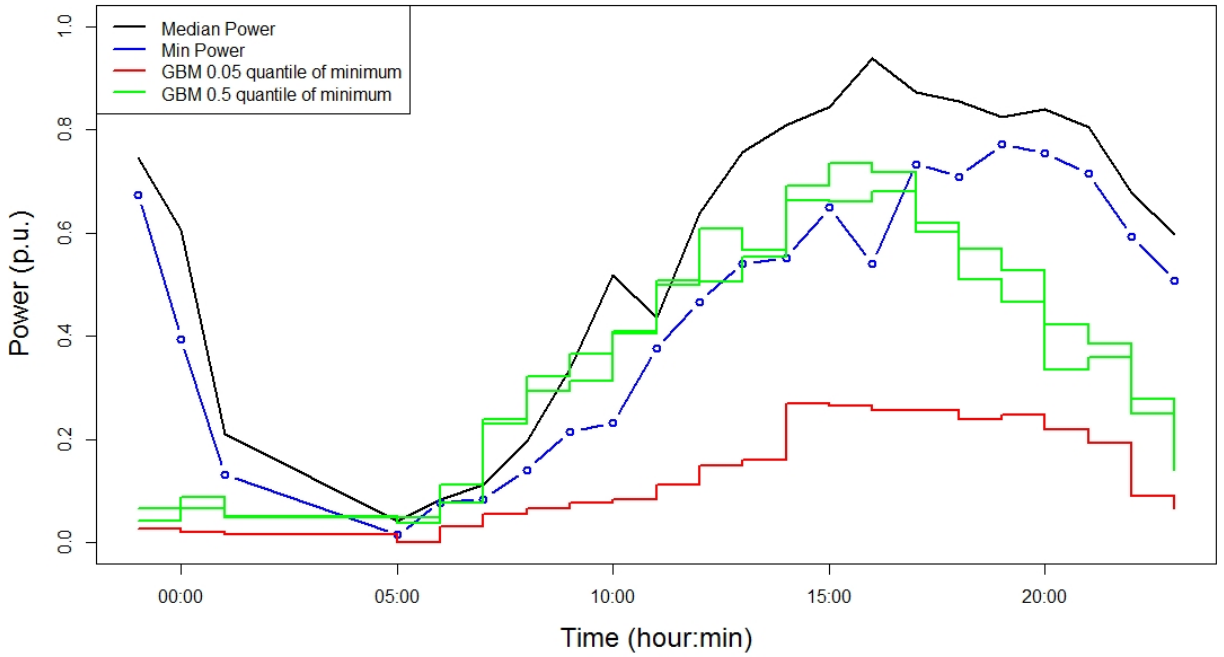
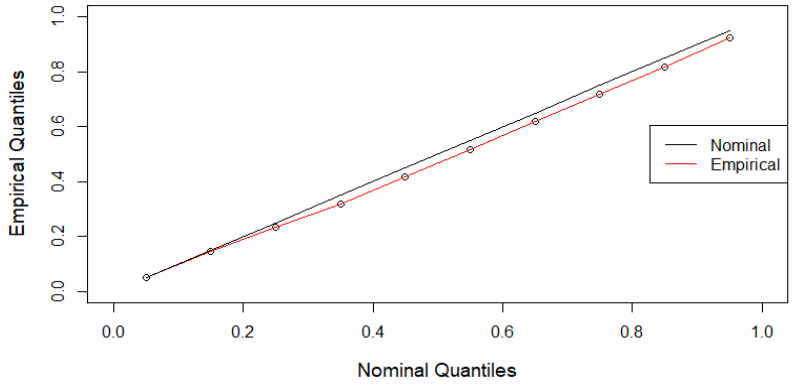
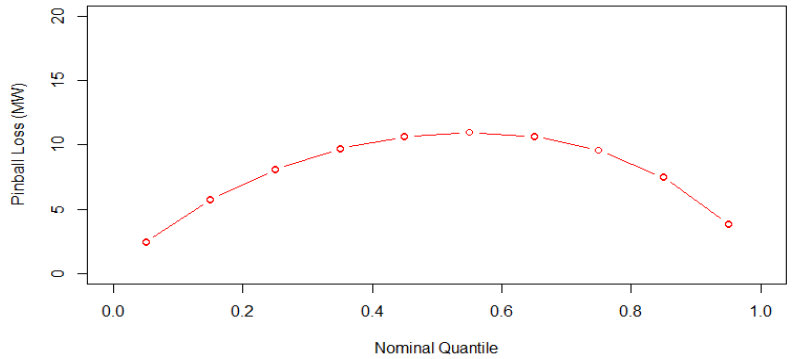


Gradient Boosted Machines (GBM)

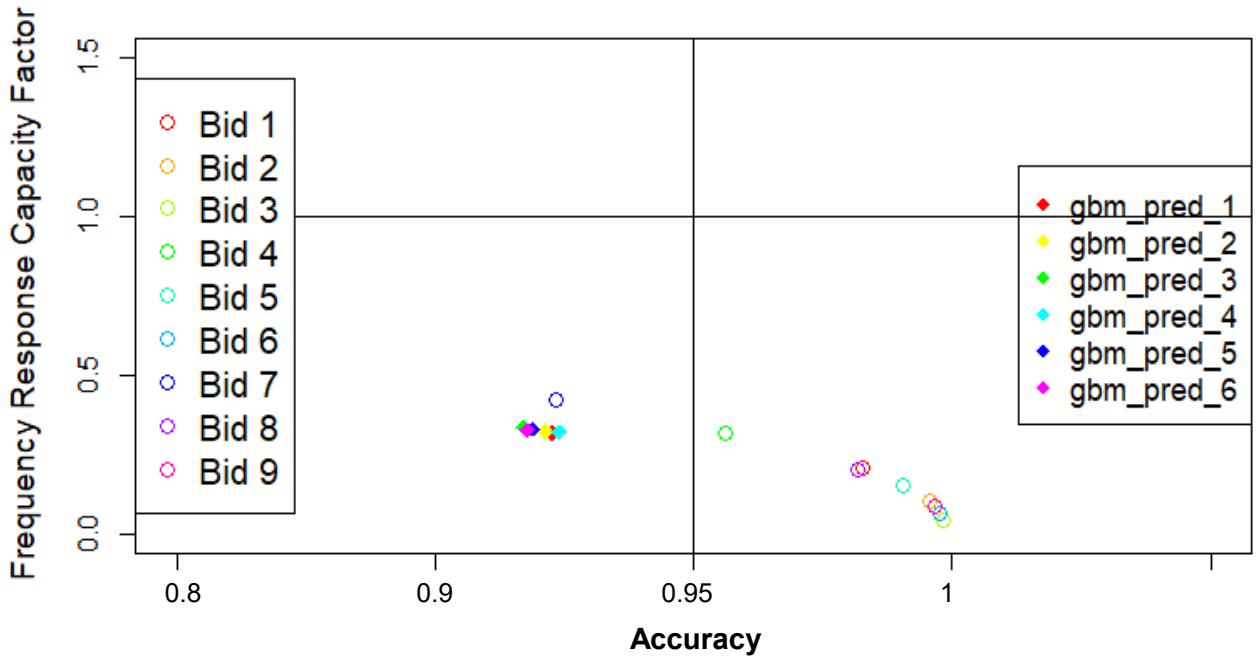
- Large input dimension machine learning technique.
    1. Separate decision trees are fitted to target using each input.
    2. Best performing decision tree selected.
    3. Residuals of best tree become new target to which all inputs are applied.
- Boosted model is weighted sum of consecutive descion trees.





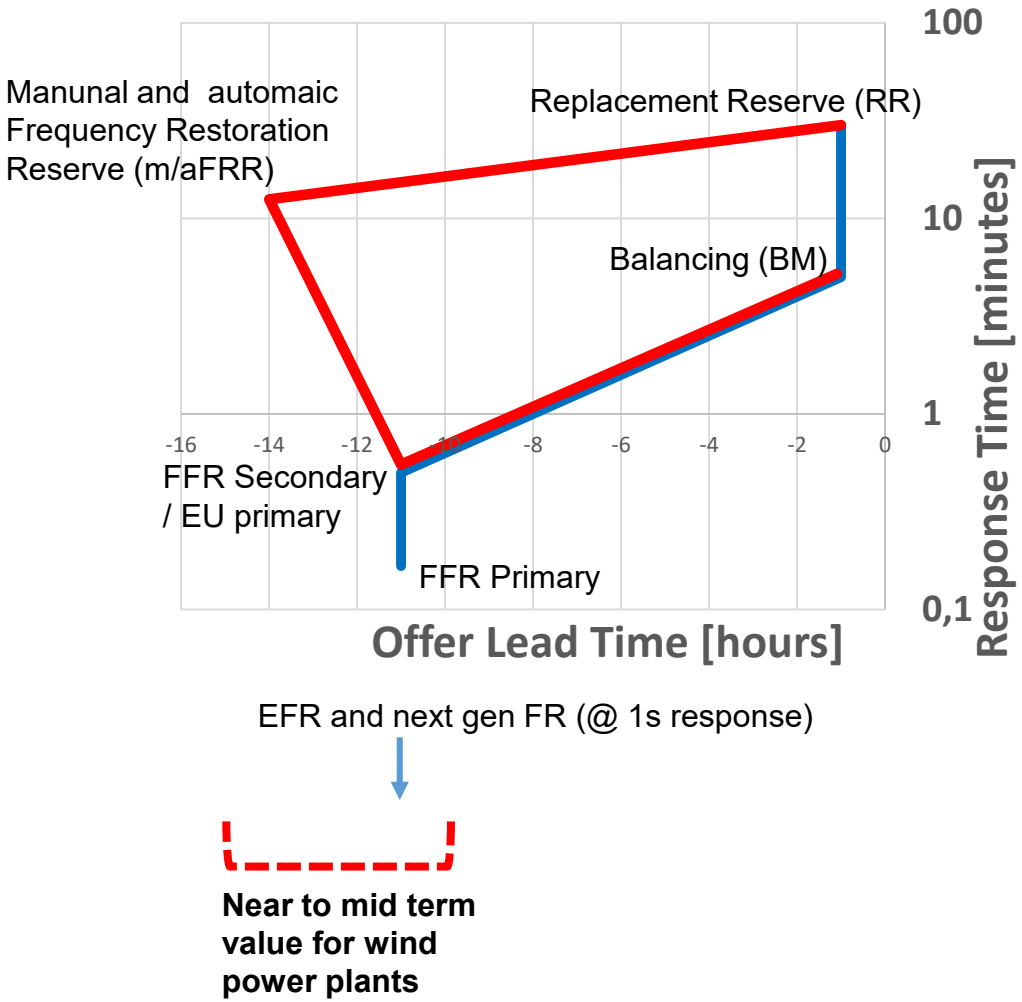
GBM Performance and Comparison

- During optimization, pinball loss and CRPS scores are used alongside reliability plots.
- As a measure of comparing forecast effectiveness, the FRCF is plotted with reliability alongside he benchmark.



Forecast Interactions

- Day ahead capacity assignments:
  - Day ahead market (mean power)
  - Frequency Response (minimum power)
  - Automatic or manual frequency restoration reserve (0.25 e-quantile i.e. quarter hour minimum)
- T-1 hours gate closure assignments:
  - Intra day market (mean power)
  - Replacement Reserve (median power i.e. 30 minute minimum power)
  - Balancing market (short term mean power)



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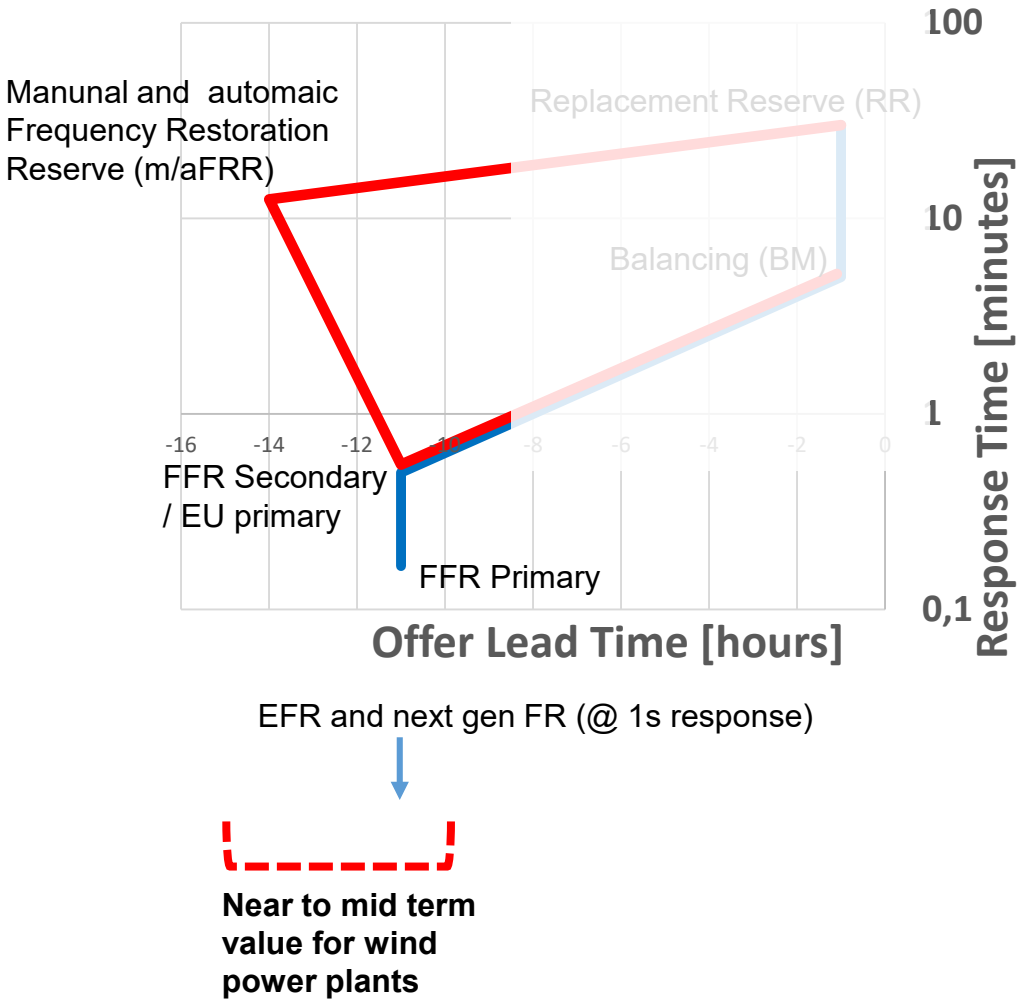
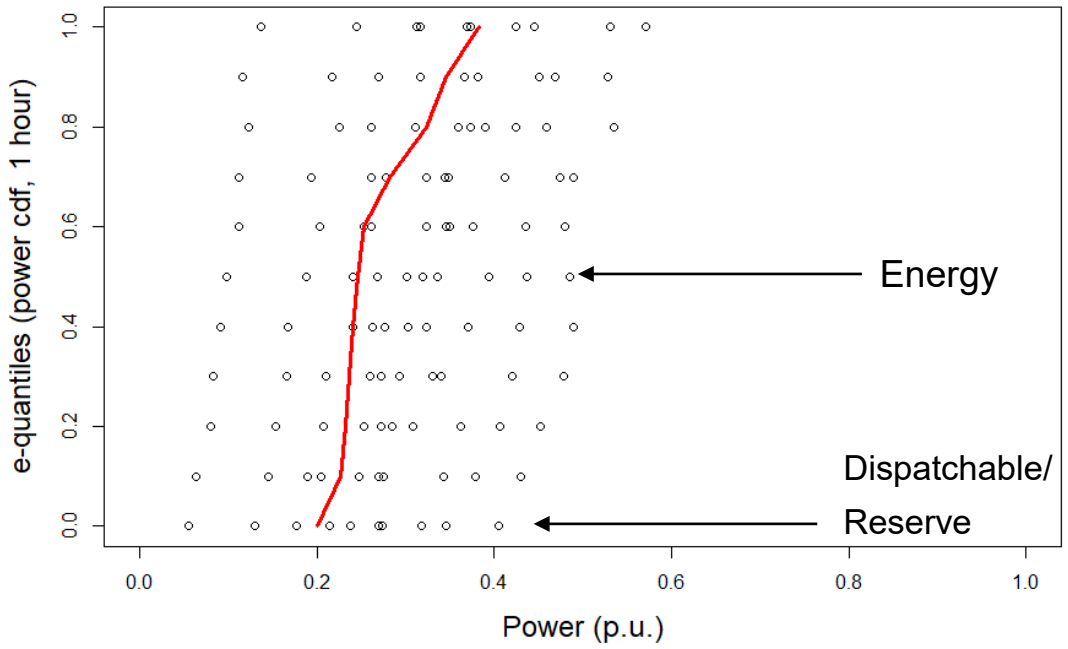


Forecast Interactions

- Multiple forecast targets at day ahead.
- Varying forecast skill
- Combining forecasts should improve aggregate accuracy and situational awareness for offer strategies



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