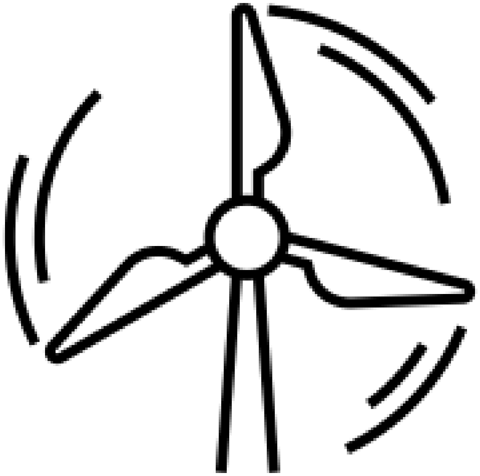
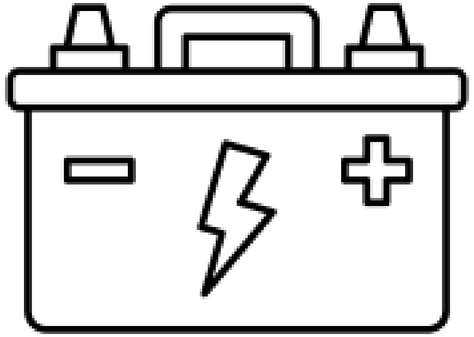




HPSC 2021

Technical and economical value of utility-scale wind-storage hybrid power plants

Mihir Mehta, Gijs van Holthoon,
Dominic von Terzi, Michiel Zaaijer

TU Delft Delft University of Technology

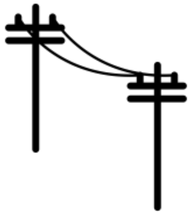
Importance of wind-storage HPP

Benefits

Energy arbitrage

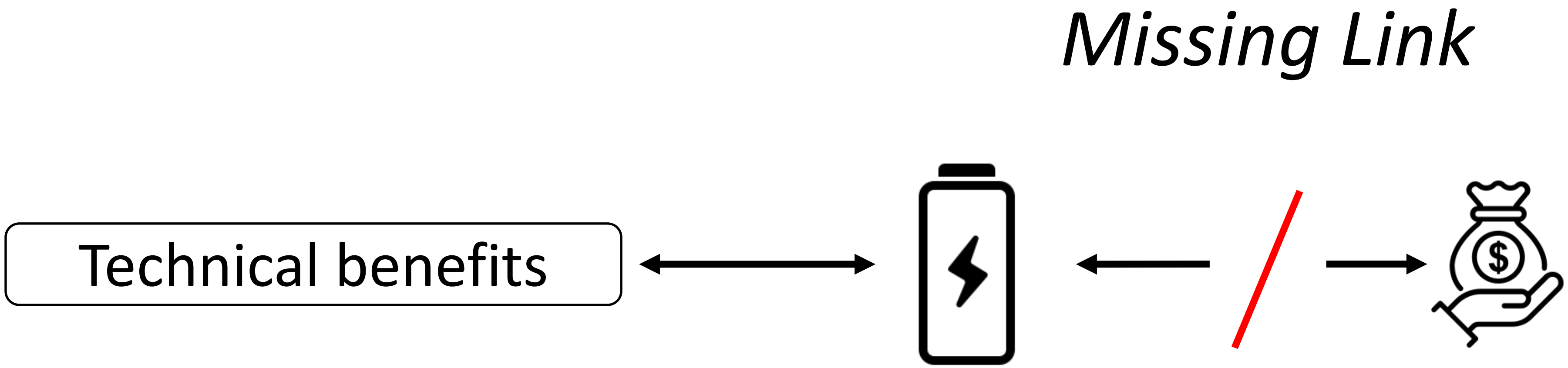
Reduction of power imbalances (from forecast errors)

Ancillary services (Frequency support)



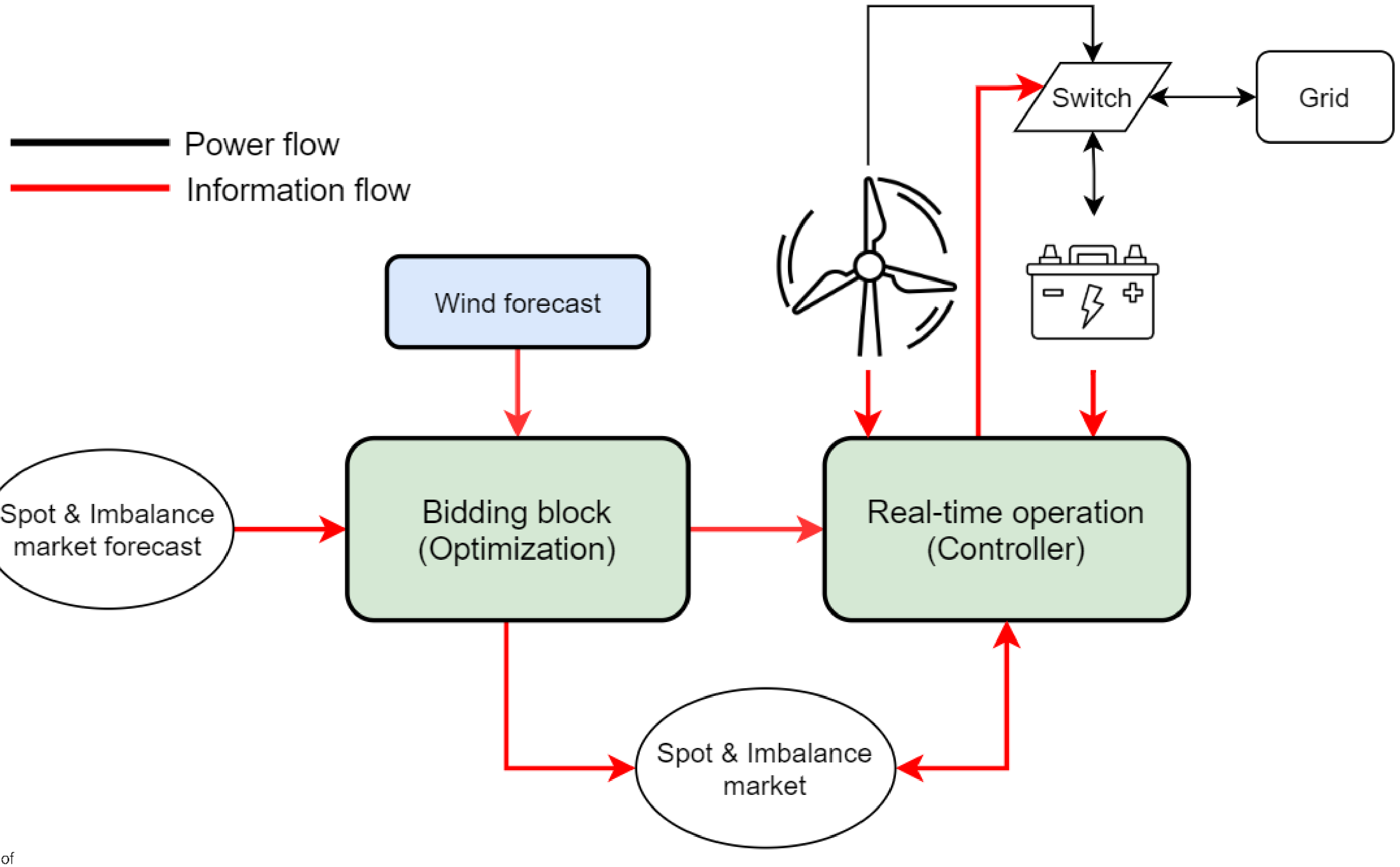
Grid congestion relief

Research Objective



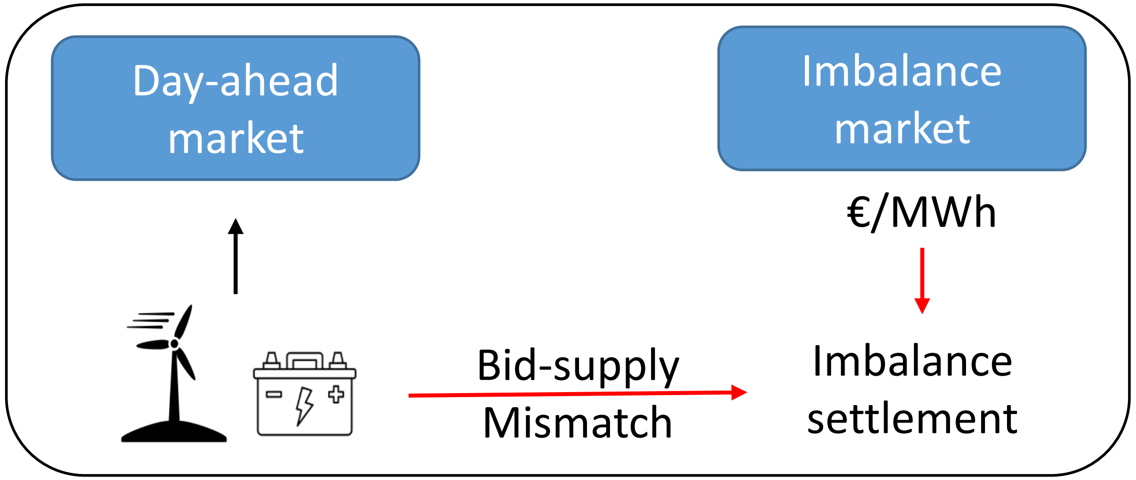
‘The objective is to establish, by quantitative analysis, the scenarios under which wind-battery HPP could be economically beneficial from a generator point of view.’

Wind-storage HPP

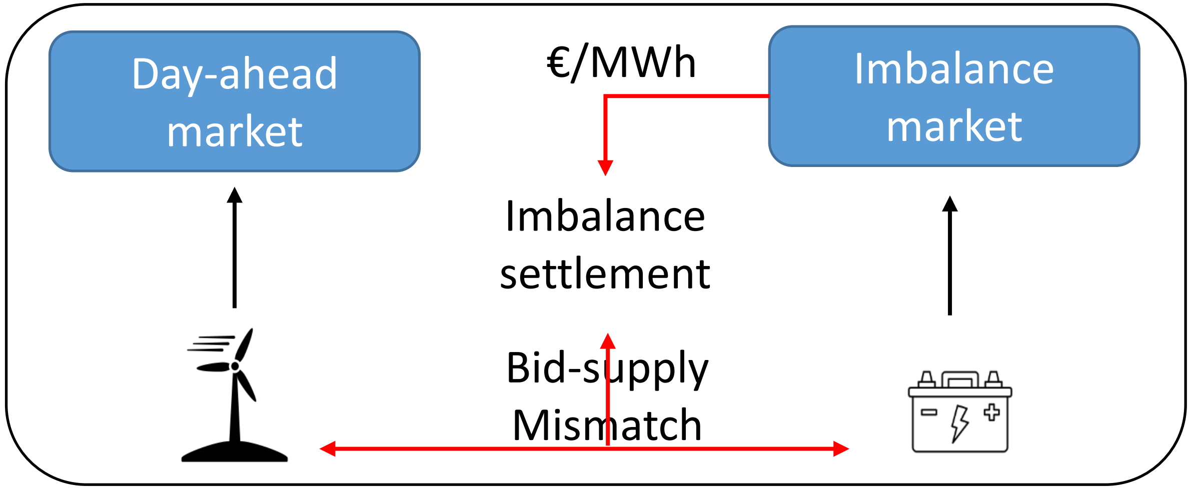


Storage applications

Arbitrage + Imbalance revenue maximization



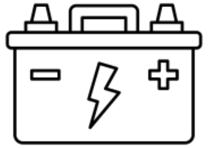
Ancillary services + Wind imbalance reduction



Case study

5 MW – 128 m
Cost - $1870/kW

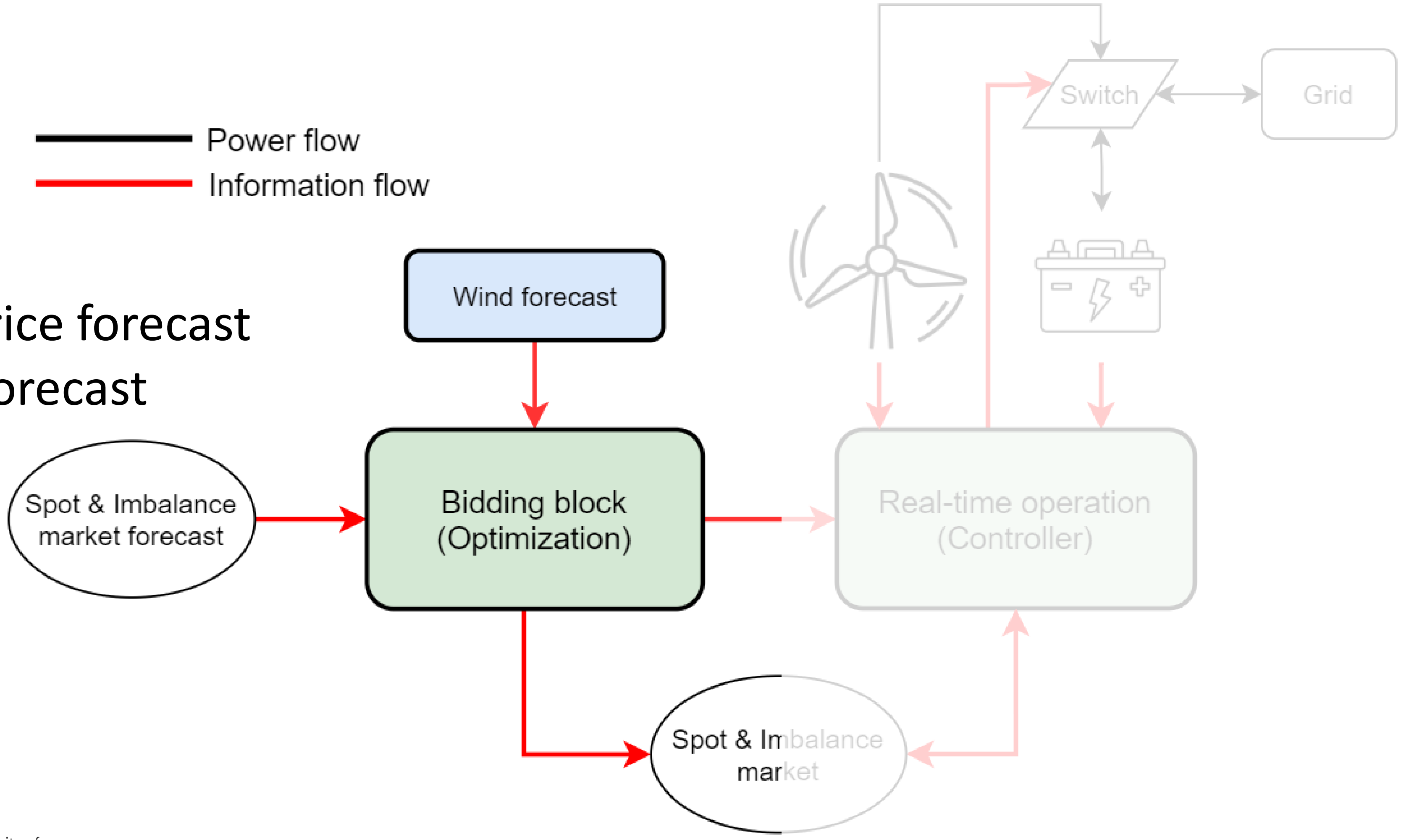
Netherlands - 2019



Li-ion
Duration – [1, 4, 8] hr
Cost – [530, 350, 290] $/kWh

Application 1: Arbitrage (Optimization)

- Spot price forecast
- Wind forecast



Application 1: Arbitrage (Optimization)

Wind power forecast *Spot price forecast*

Objective function

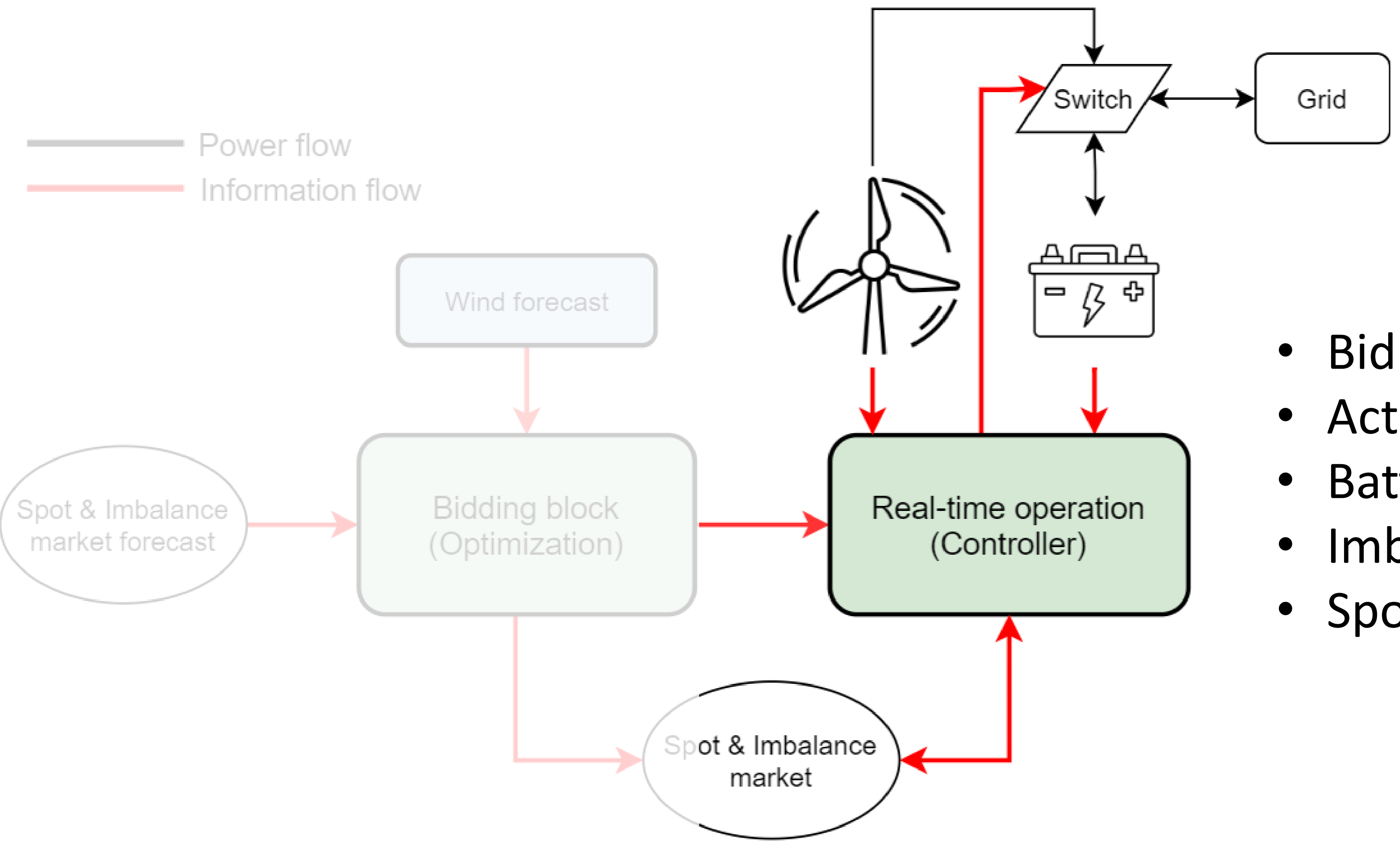
$$\max_{x} f(x) = \sum_{t=1}^{96} (P_{wind}(t) + x_{dis}(t) - x_{cha}(t)) \,.\, \lambda_{DAM}(t)$$

Design variables

Constraints

$$\text{s.t.} \quad 0 < x_{dis}(t) < P_{cap}$$
$$0 < x_{cha}(t) < P_{cap}$$
$$0.3 < SOC(t) < 1$$
$$SOC(t=97)_{act} = SOC(t=97)_{forc}$$
$$SOC(t=97)_{D} = SOC(t=1)_{D+1}$$

Application 1: Arbitrage (Real-time)

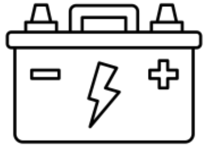
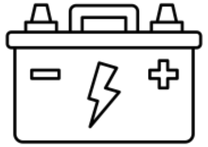


- Bid volume
- Actual wind generation
- Battery SOC
- Imbalance prices
- Spot prices

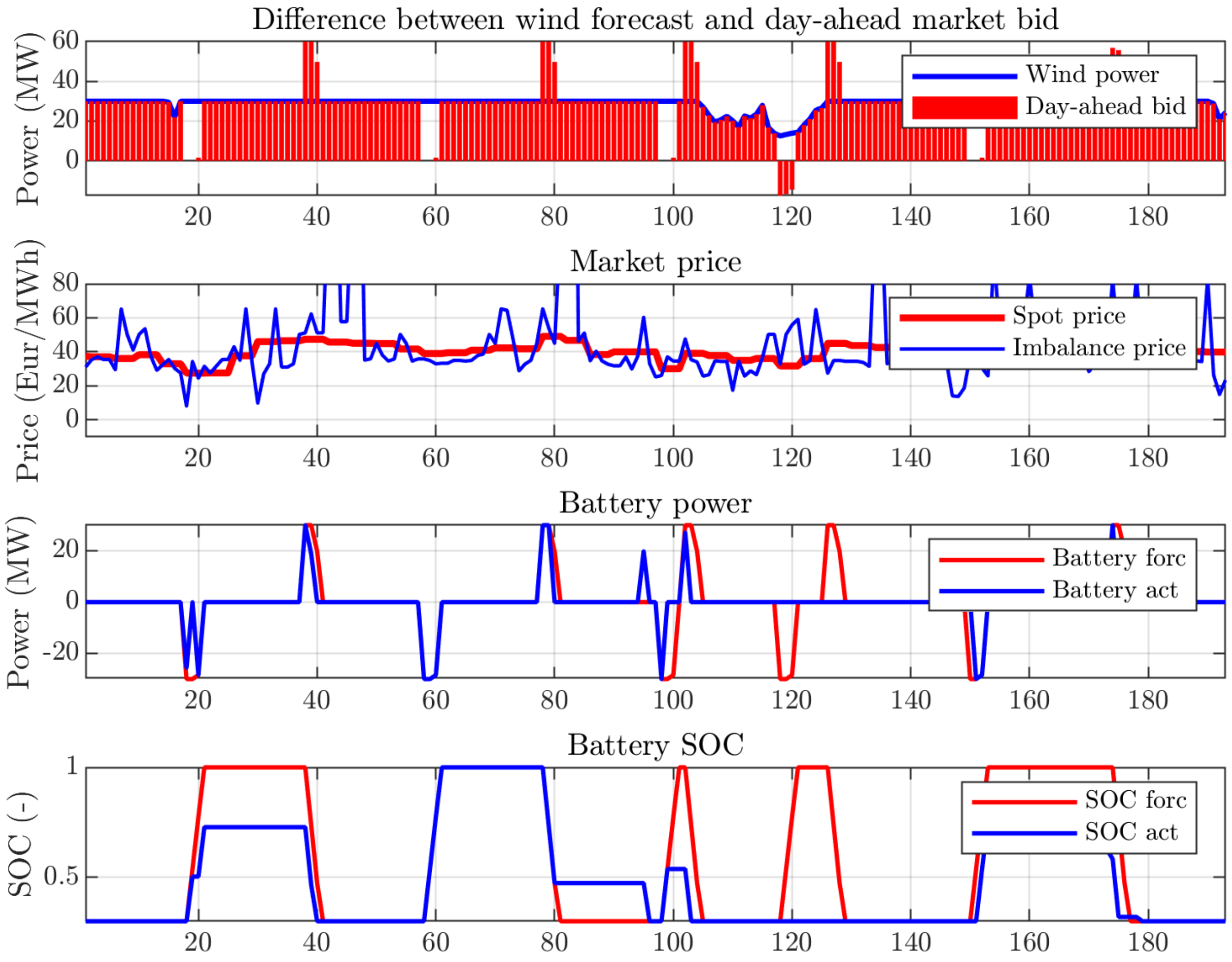
Application 1: Arbitrage (Real-time)

$P_{diff} = P_{wind} - P_{bid}$

$\delta = \lambda_{imb} - \lambda_{spot}$

	$P_{diff} < 0$	$P_{diff} > 0$
$\delta > 0$	Discharge 	Sell to imbalance market
$\delta < 0$	Buy from imbalance market	Charge 

Application 1: Arbitrage (Illustration)



120^{th} time stamp

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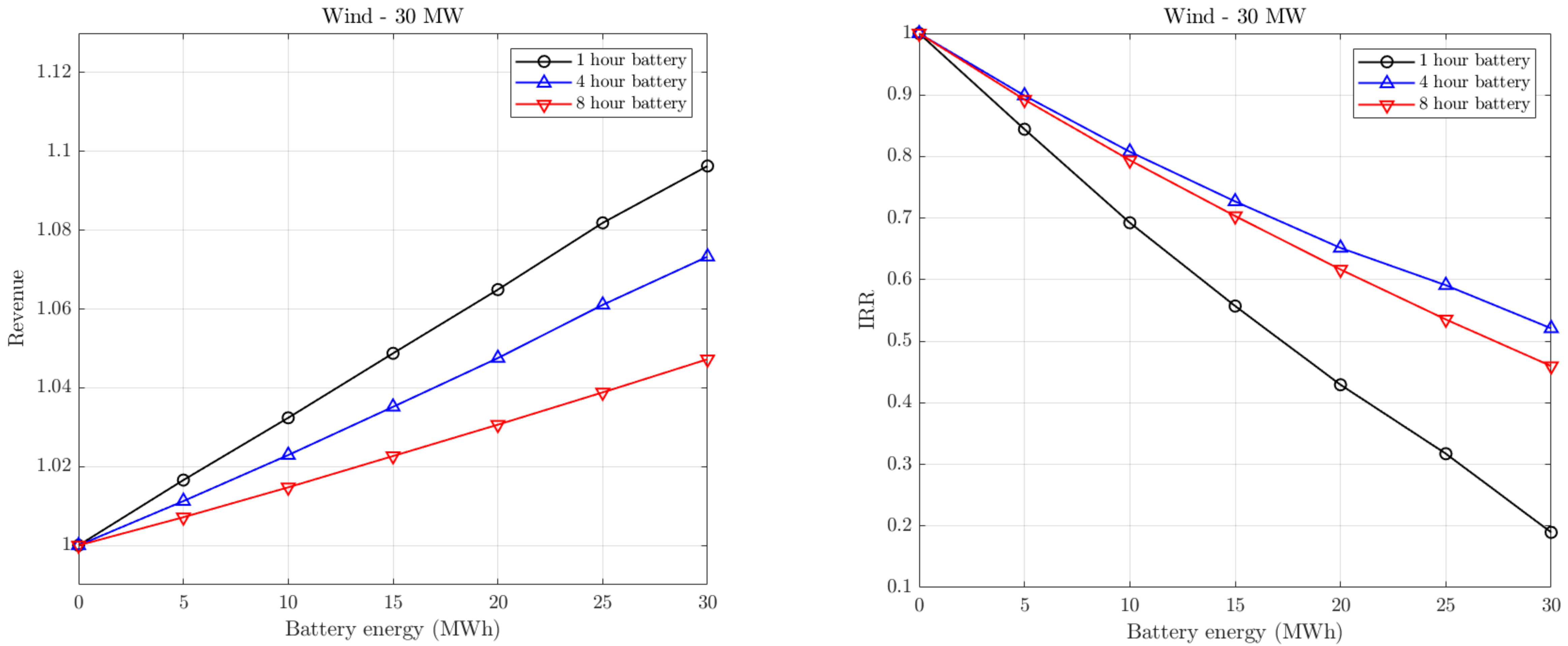
Application 1: Arbitrage (Economics)



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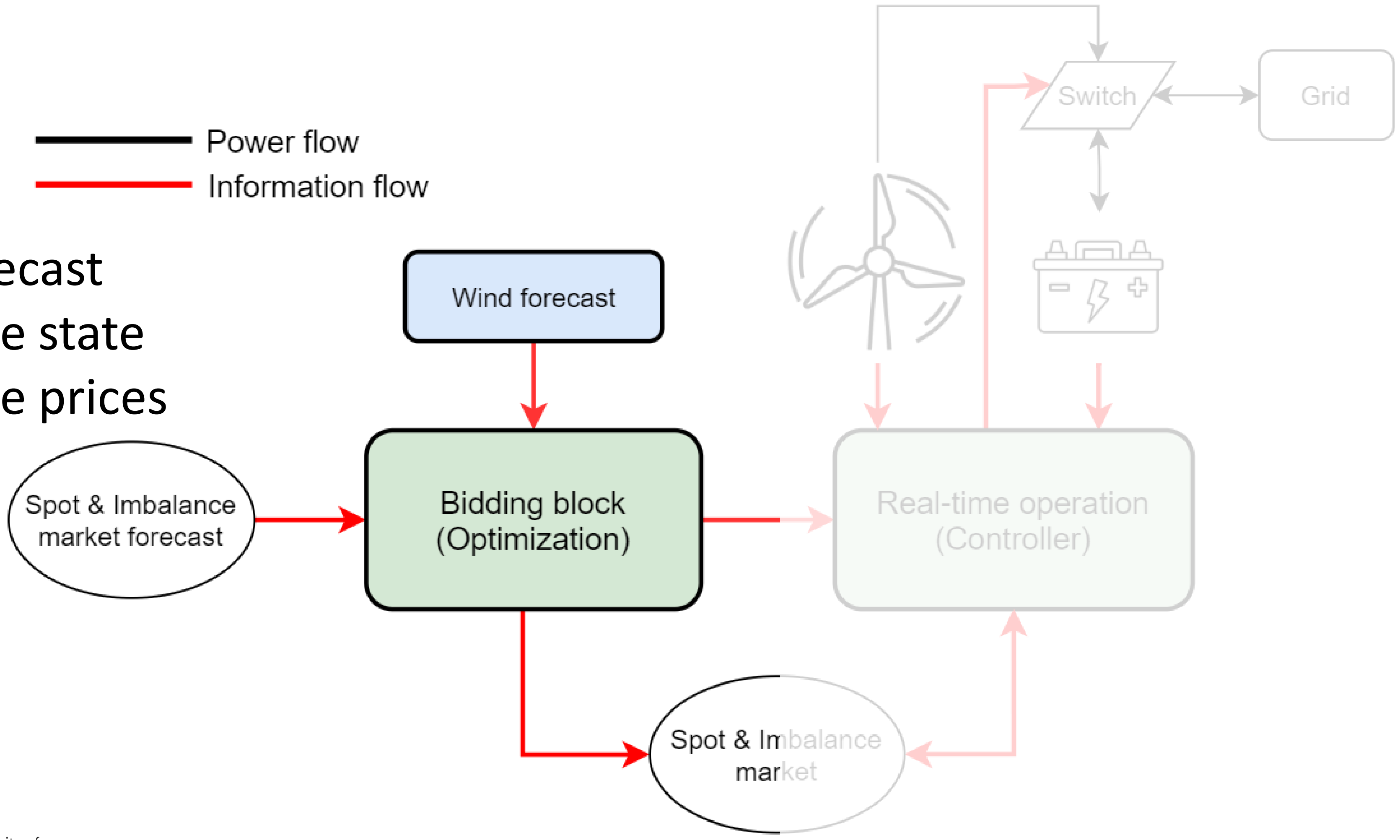
Application 2: Ancillary services (Optimization)

- Wind forecast
- Imbalance state
- Imbalance prices



Application 2: Ancillary services (Optimization)

Capacity remuneration

Energy remuneration

Imbalance price forecast

Objective function

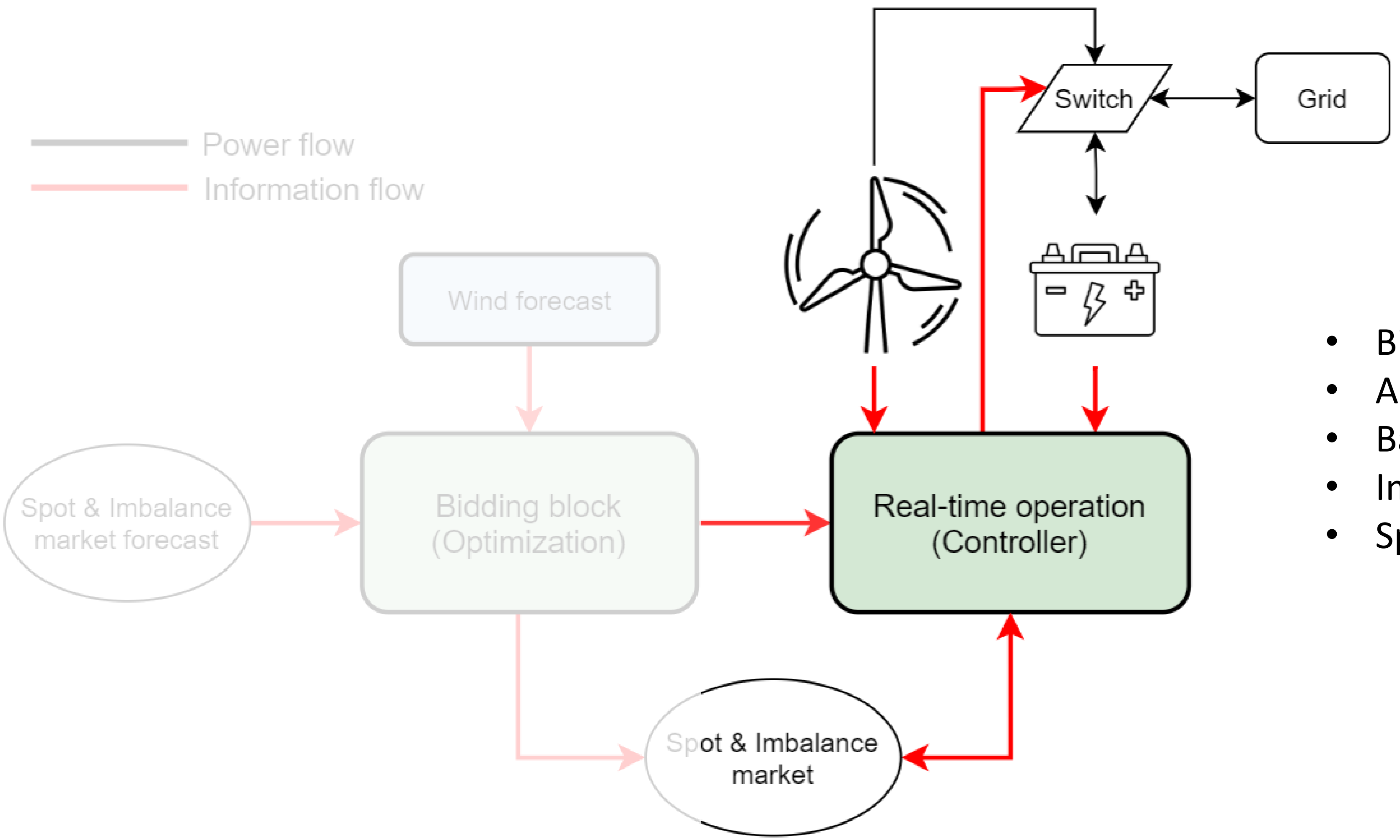
$$\max_{x} f(x) = (x_{up} + x_d) . 24 . \lambda_{cap} + \sum_{t=1}^{96} (x_{up} . \beta_{up}(t) - x_d . \beta_d(t)) . (1/4) . \lambda_{imb}(t)$$

Design variables

Constraints

$$\begin{aligned} \text{s.t.} \quad & 0 < x_{dis}(t) < P_{cap} \\ & 0 < x_{cha}(t) < P_{cap} \\ & 0.3 < SOC(t) < 1 \\ & SOC(t=97)_{act} = SOC(t=97)_{forc} \\ & SOC(t=97)_D = SOC(t=1)_{D+1} \end{aligned}$$

Application 1: Arbitrage (Real-time)



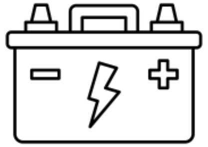
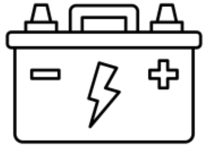
- Bid volume
- Actual wind generation
- Battery SOC
- Imbalance prices
- Spot prices

Application 2: Ancillary services (Real-time)

*** Only if it does not disturb ancillary services operation**

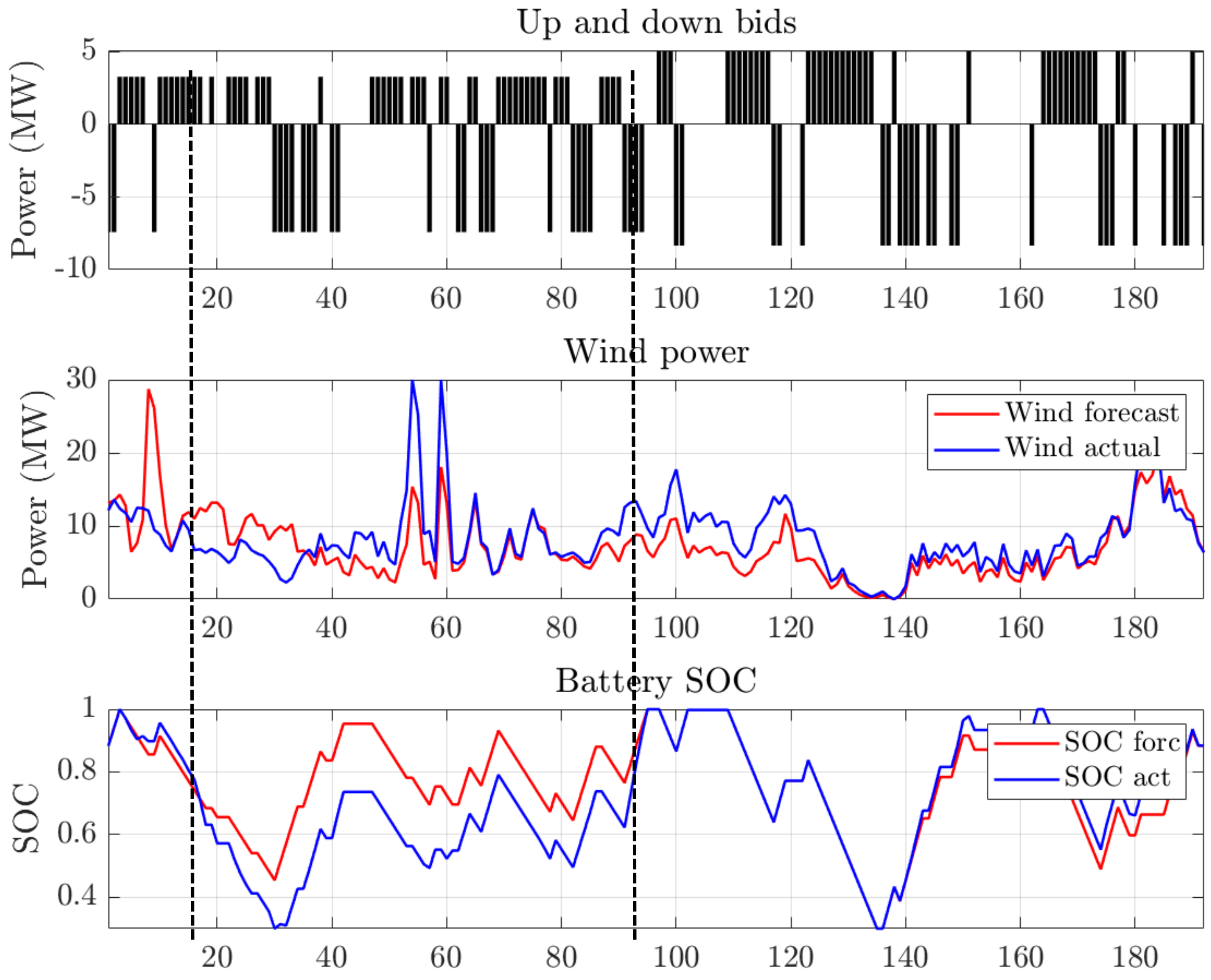
$$P_{diff} = P_{act} - P_{forc}$$

$$\delta = \lambda_{imb} - \lambda_{spot}$$

	$P_{diff} < 0$	$P_{diff} > 0$
$\delta > 0$	Discharge* 	Sell to imbalance market
$\delta < 0$	Buy from imbalance market	Charge* 

Application 2: Ancillary services (Illustration)

15th time stamp



92nd time stamp

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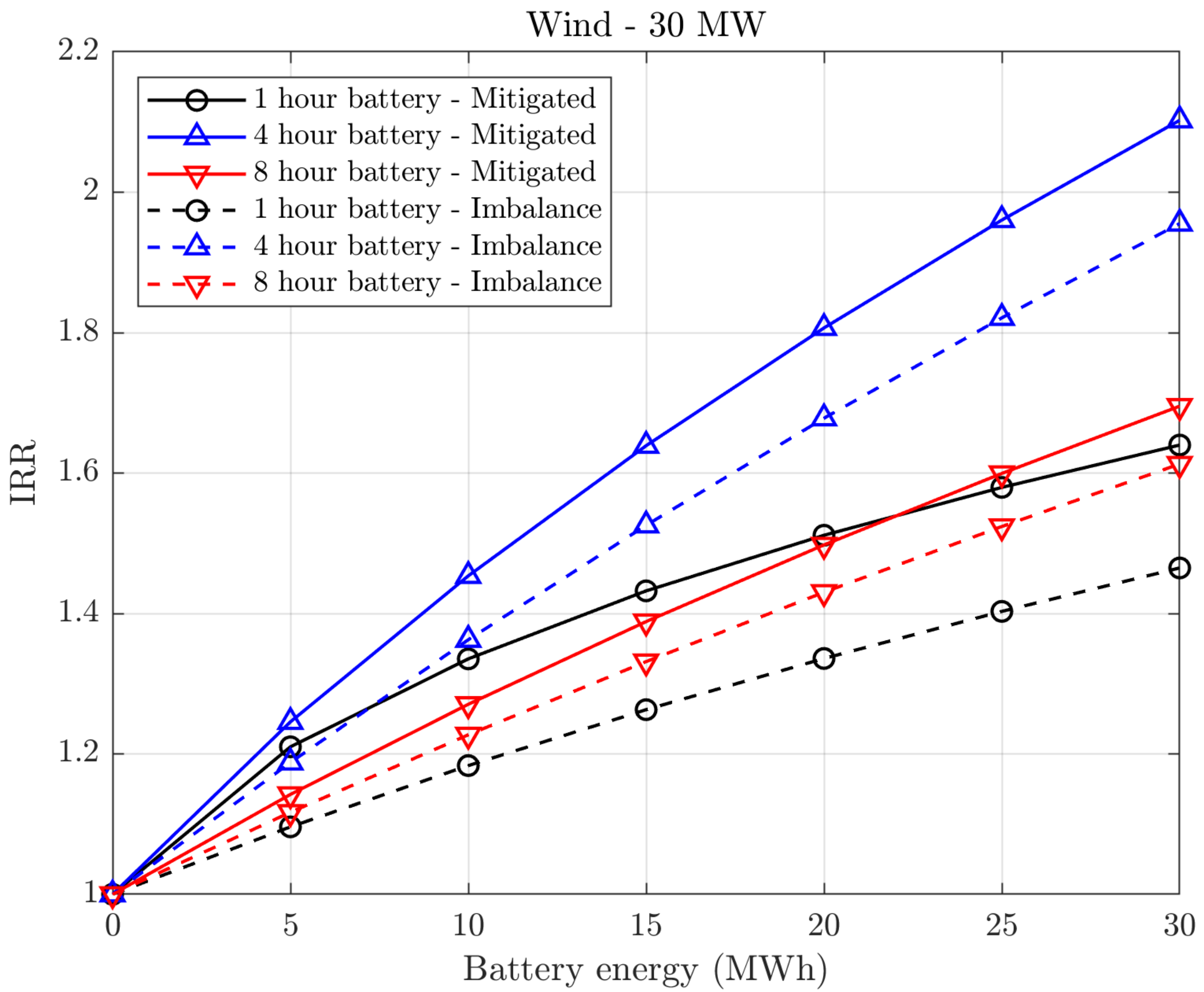
Application 2: Ancillary services (Economics)



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Main findings

Arbitrage:

- *10 % increase in revenue using a 1-hour battery (of the size of the wind farm)*
- *A 4-hour battery has a better economic case*
- *50 % cost reduction required for arbitrage to be economically attractive*

Ancillary services:

- *Strong economic case for batteries providing secondary frequency support*
- *Mainly due to the perfect market assumption*
- *Further research for a case with little to no prior information about imbalances is required*

Conclusion

‘Providing ancillary services is a more attractive economic case for adding battery storage to an existing wind plant than arbitrage.’