

# *HPSC 2021*

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

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# Importance of wind-storage HPP

Wind and storage hybrids — a marriage made in heaven?  
Adding storage to renewables is on the rise, as the US leads the way in solar-battery hybrids and wind-battery projects take off in the UK  
by Sara Verbruggen



**Wind-solar-storage hybrid offers cheaper electricity than new coal in India**

A new report establishes the feasibility of wind-solar-storage hybrid projects over new coal plants in the Indian states with high renewable energy potential. Tamil Nadu was chosen for the technical and commercial assessment.

JANUARY 22, 2021 UMA GUPTA

UNITED STATES  
**WindPlus: Falling costs will drive growth in hybrid projects for key states**



HOME > NEWSROOM > NEWS AND STORIES > ARCHIVE > 2018 > RENEWABLE: BALANCI...  
**Renewable: Balancing with batteries**

Solar cells generate power when the sun shines, and wind turbines when the wind blows, but not necessarily when the need for energy is greatest. Can batteries store renewable energy "in a can" - for later use?

## Benefits



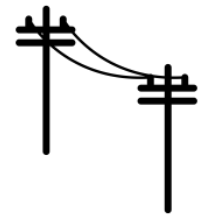
Energy arbitrage



Reduction of power imbalances (from forecast errors)



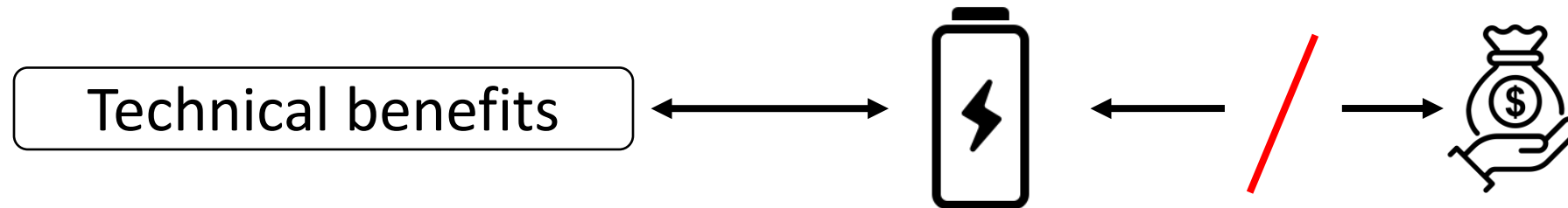
Ancillary services (Frequency support)



Grid congestion relief

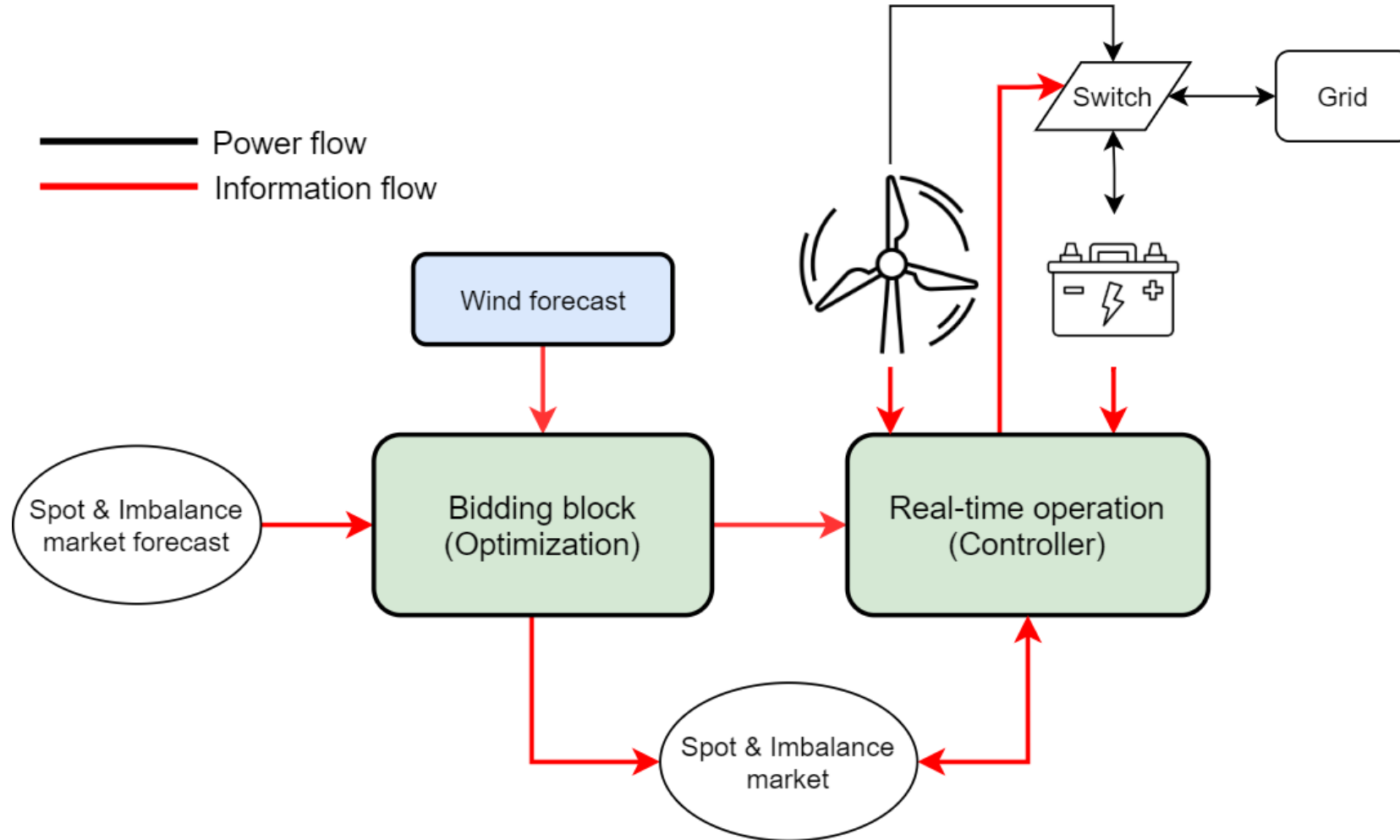
# Research Objective

## Missing Link



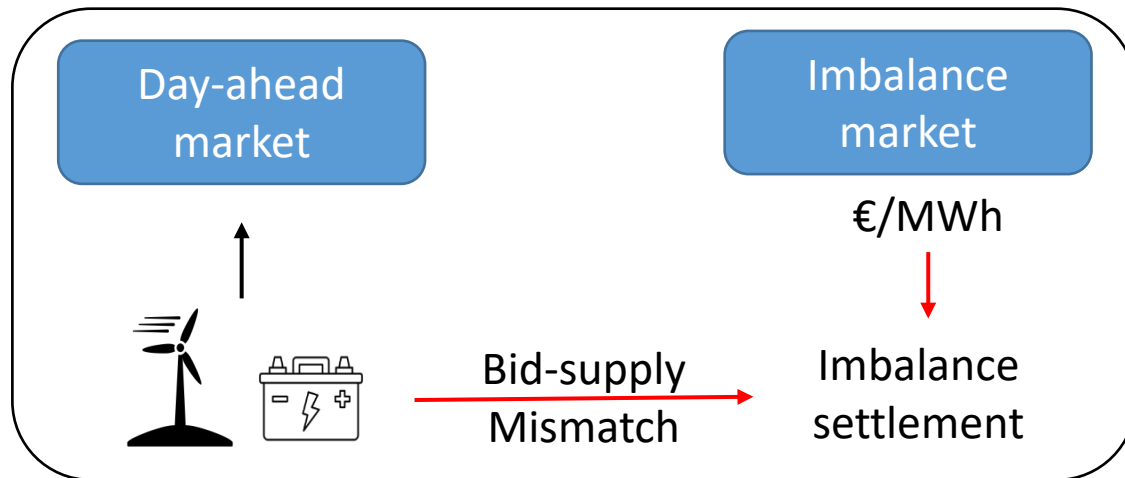
*‘The objective is to establish, by quantitative analysis, the scenarios under which wind-battery HPP could be economically beneficial from a generator point of view.’*

# Wind-storage HPP

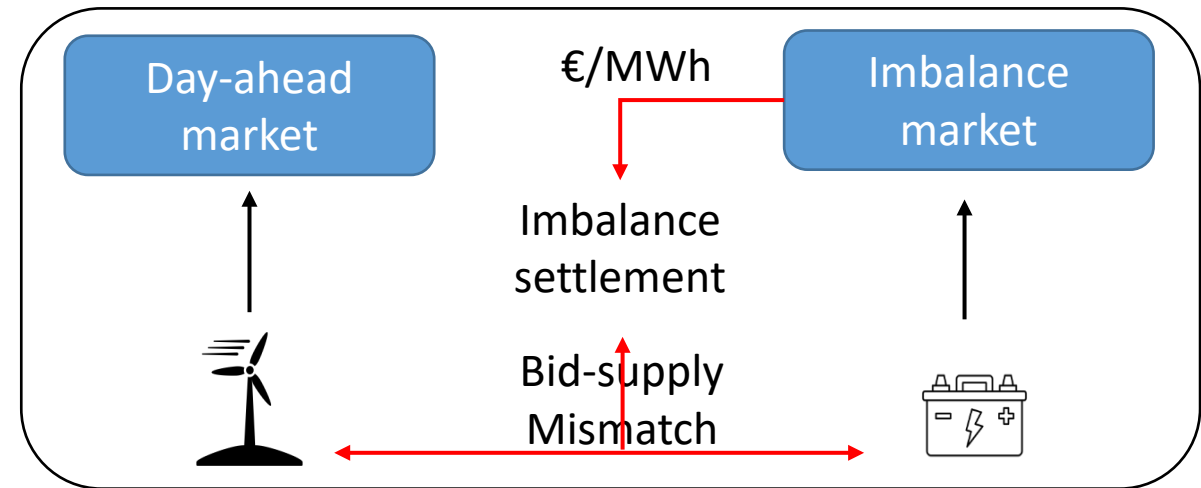


# Storage applications

*Arbitrage + Imbalance revenue maximization*



*Ancillary services + Wind imbalance reduction*



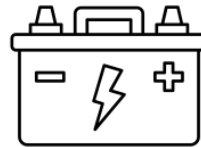
# Case study



5 MW – 128 m  
Cost - \$1870/kW



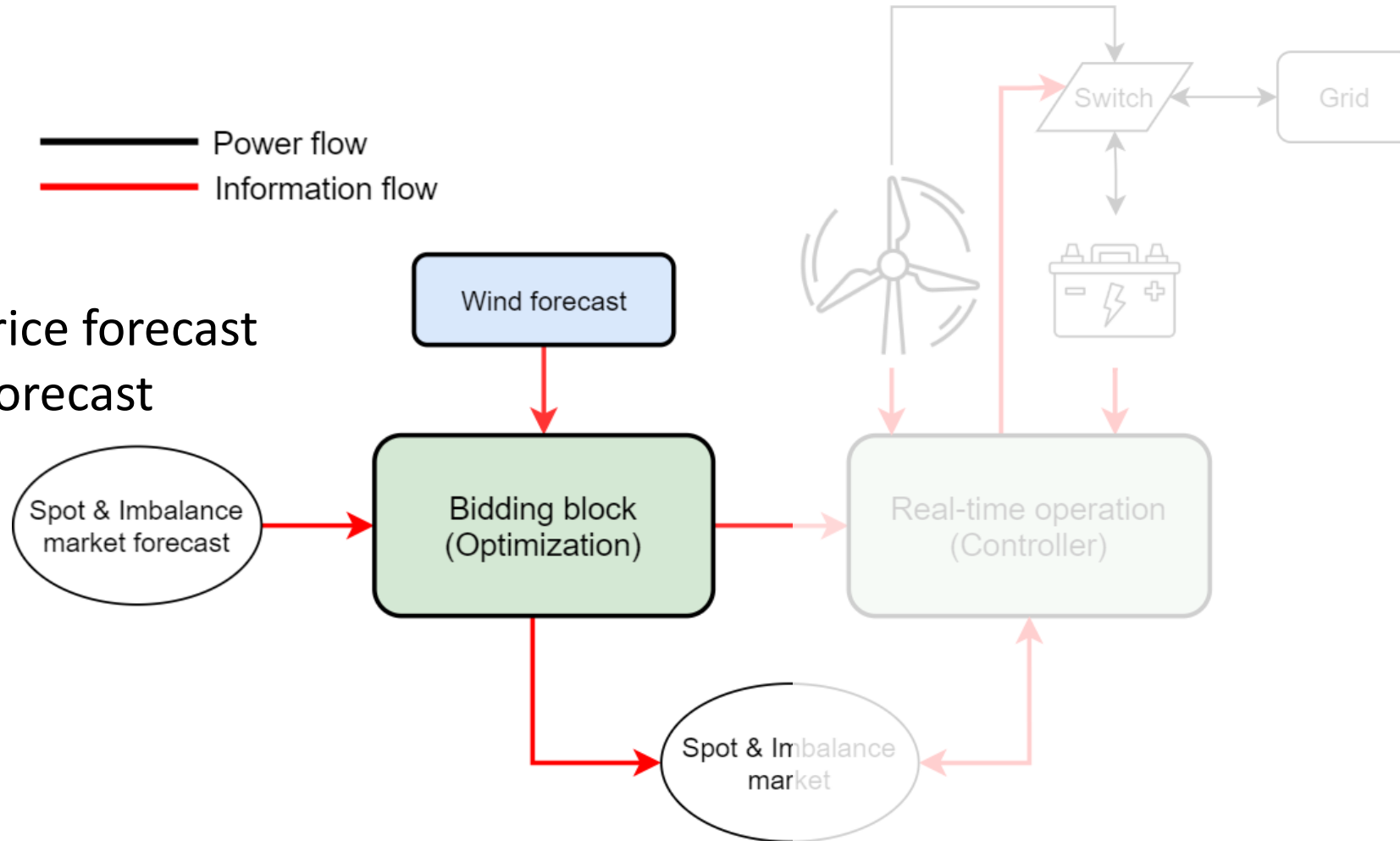
Netherlands - 2019



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)

*Objective  
function*

*Wind power forecast* ↓      *Spot price forecast* ↓

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

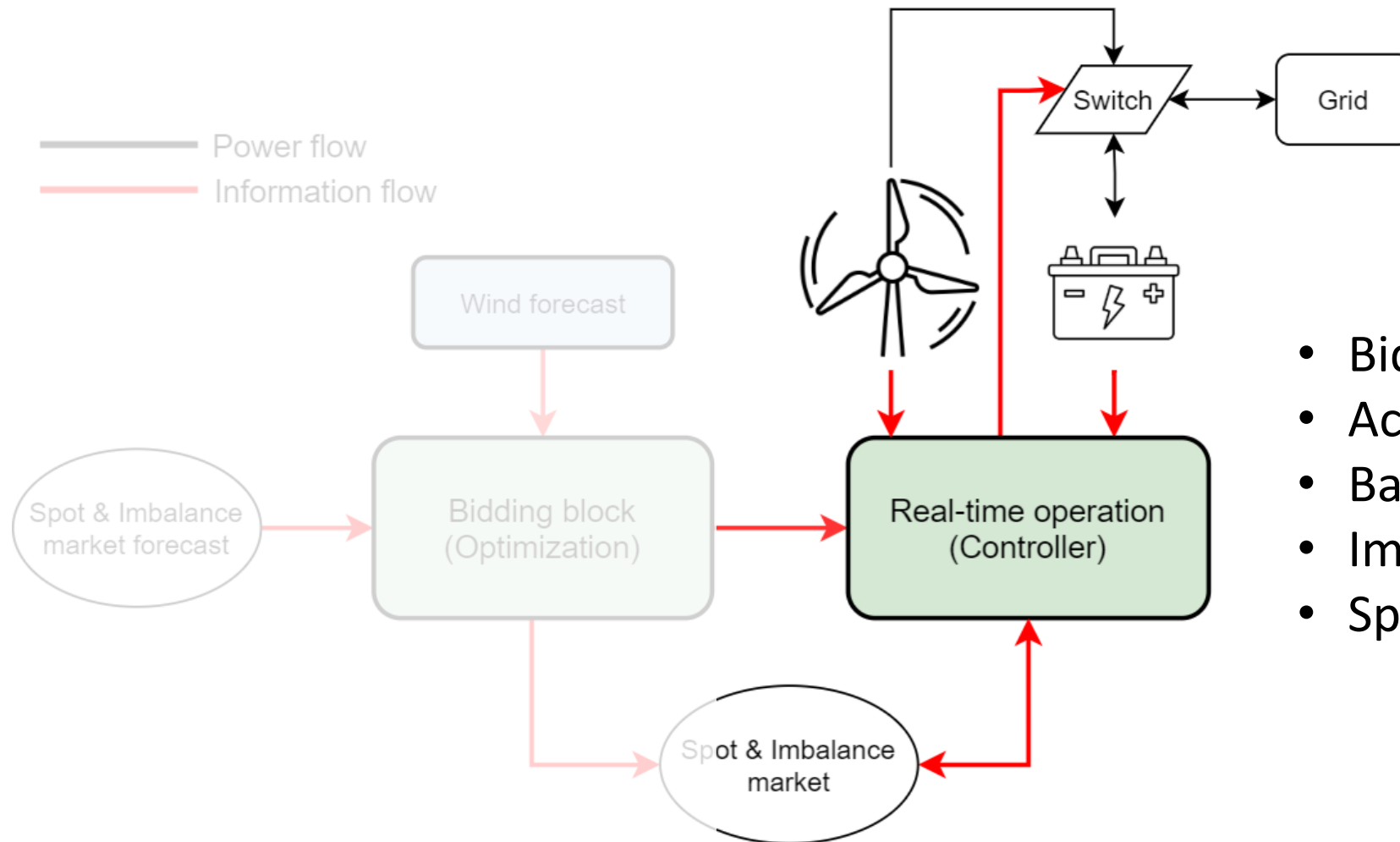
↙ ↘  
*Design variables*

## *Constraints*

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



# Application 1: Arbitrage (Real-time)

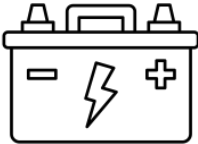
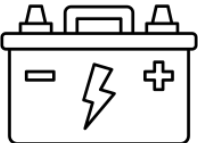


- Bid volume
- Actual wind generation
- Battery SOC
- Imbalance prices
- Spot prices

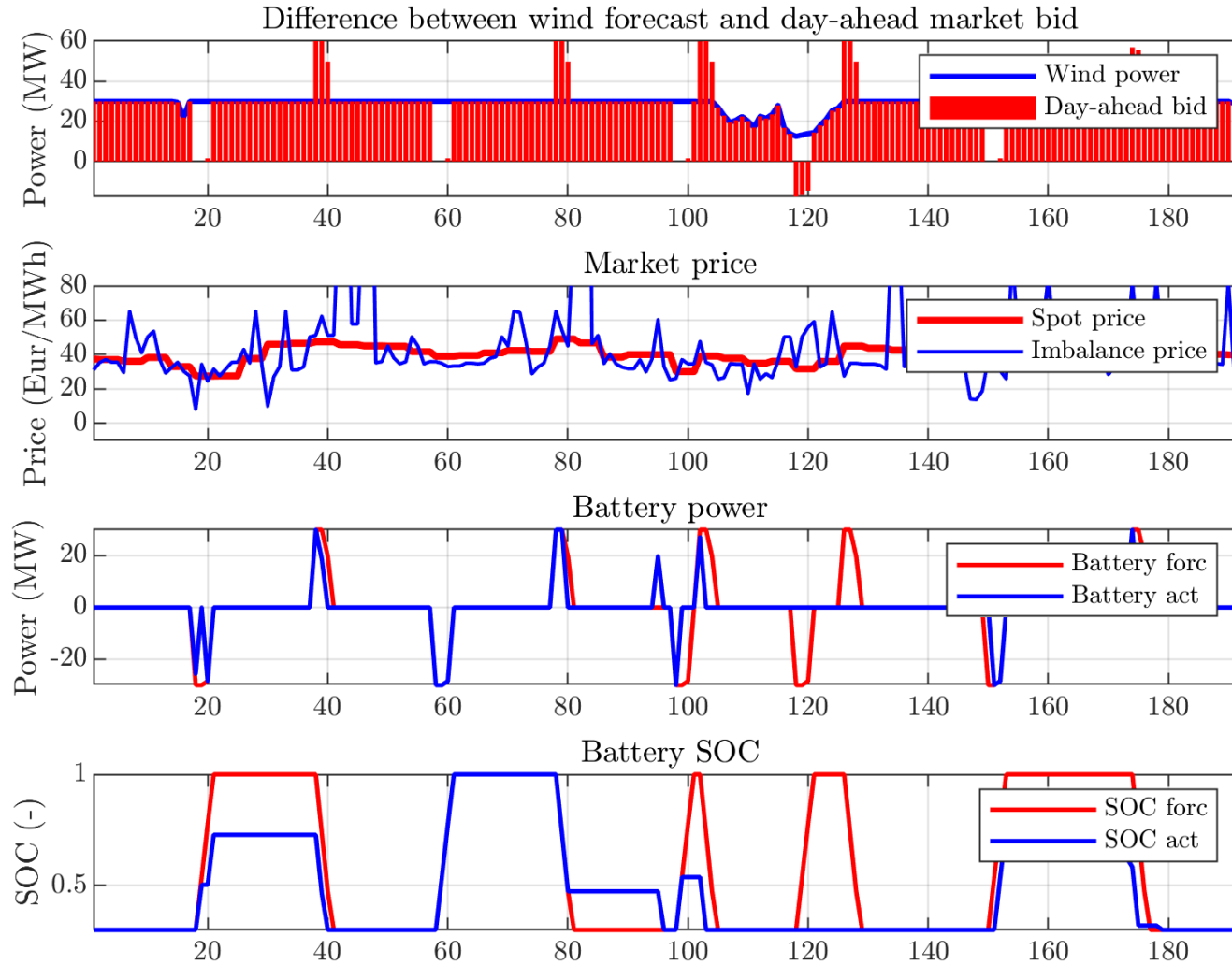
# Application 1: Arbitrage (Real-time)

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

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

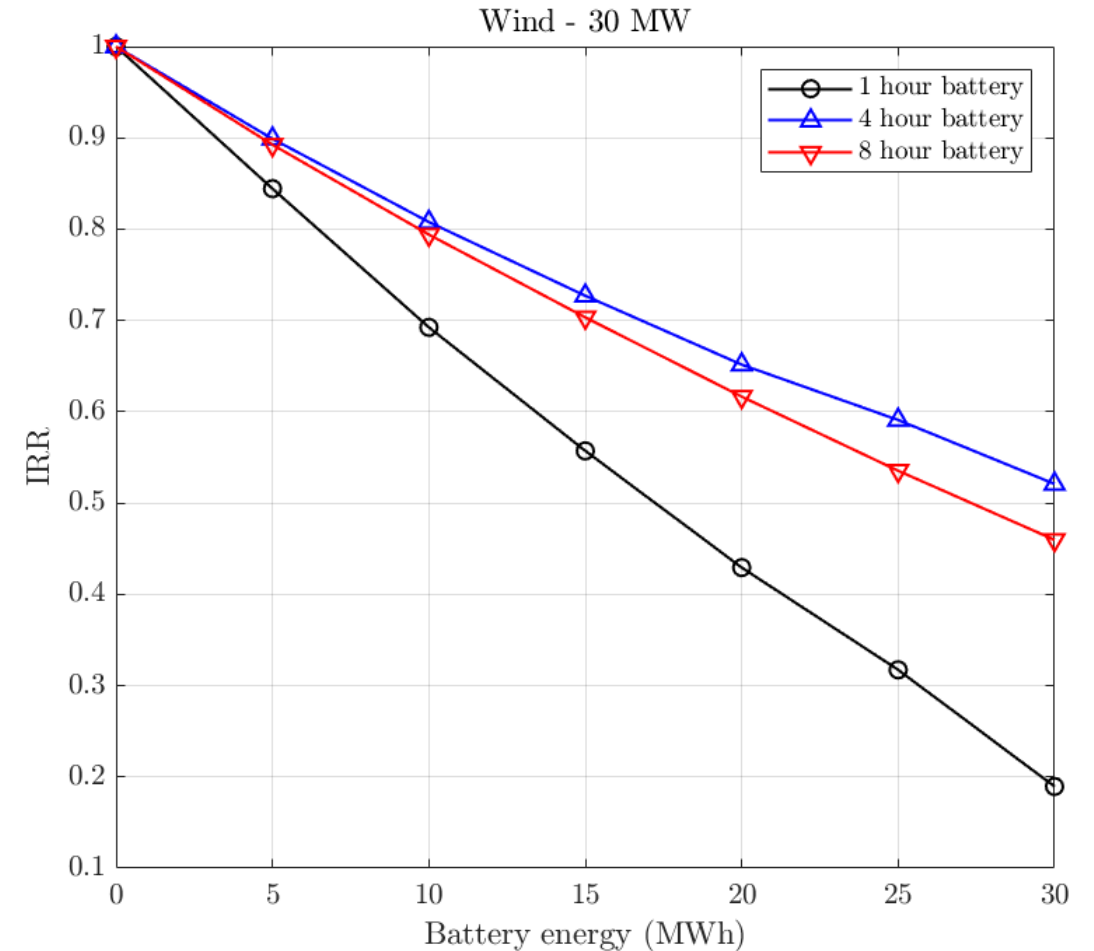
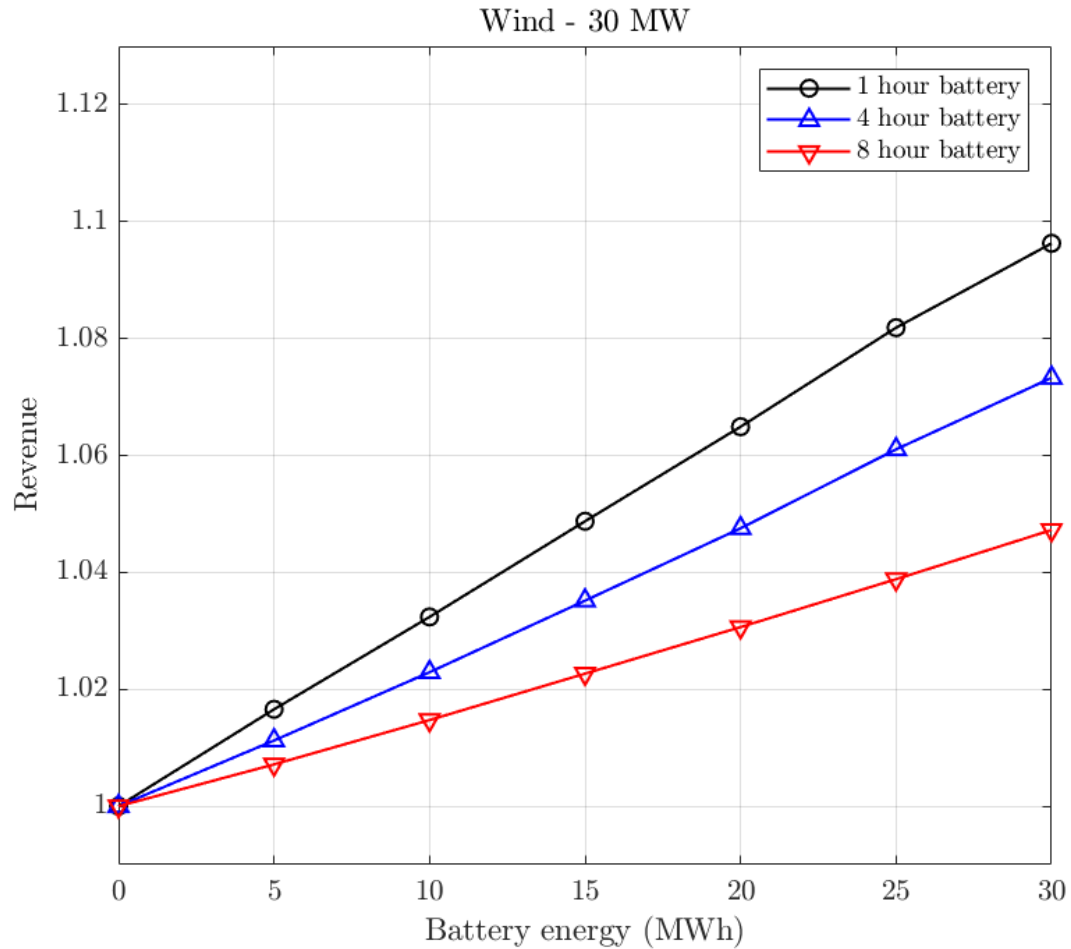
	$P_{diff} < 0$	$P_{diff} > 0$
$\delta > 0$	Discharge 	Sell to imbalance market
$\delta < 0$	Buy from imbalance market	Charge 

# Application 1: Arbitrage (Illustration)



*120<sup>th</sup> time stamp*

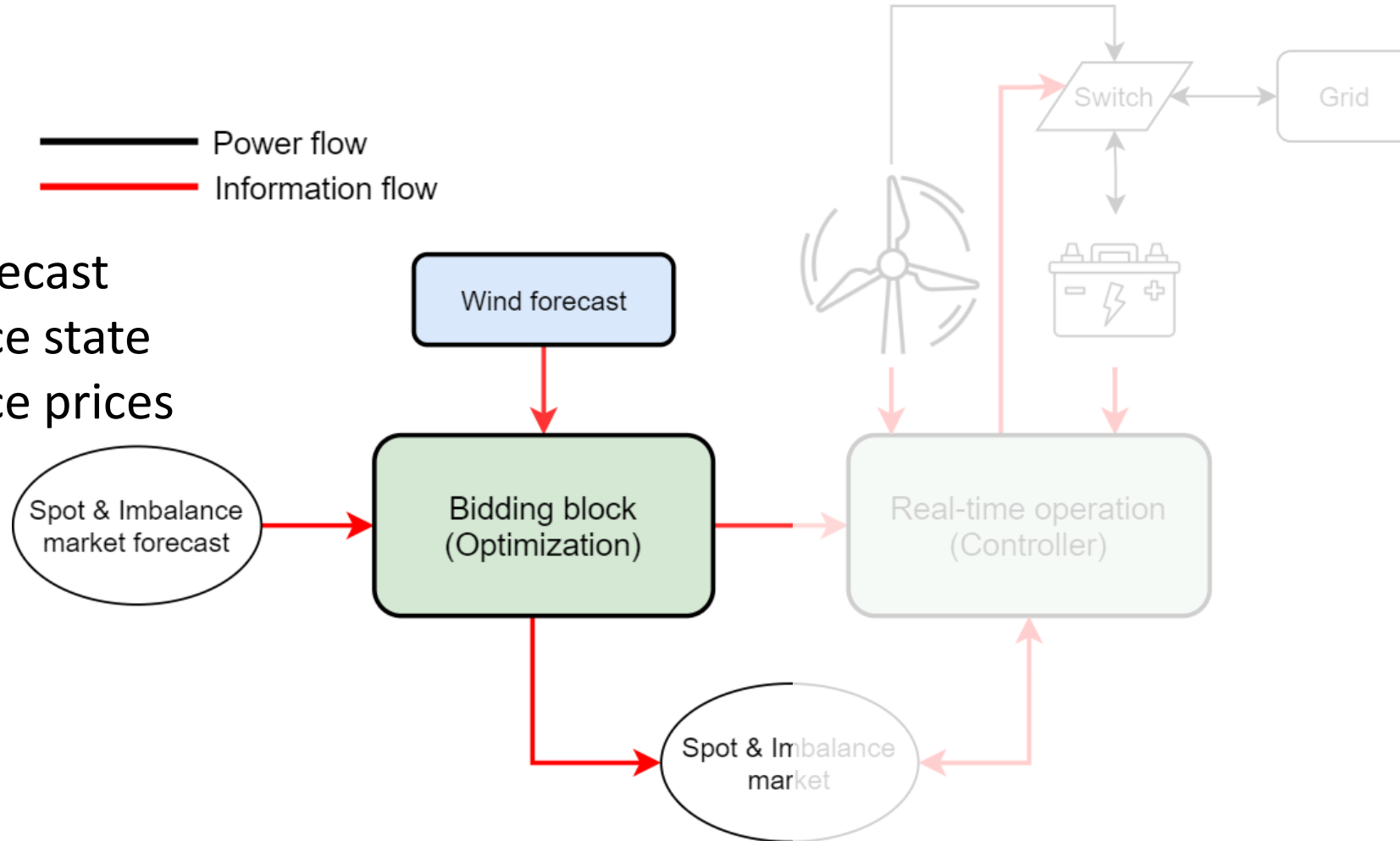
# Application 1: Arbitrage (Economics)



# 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

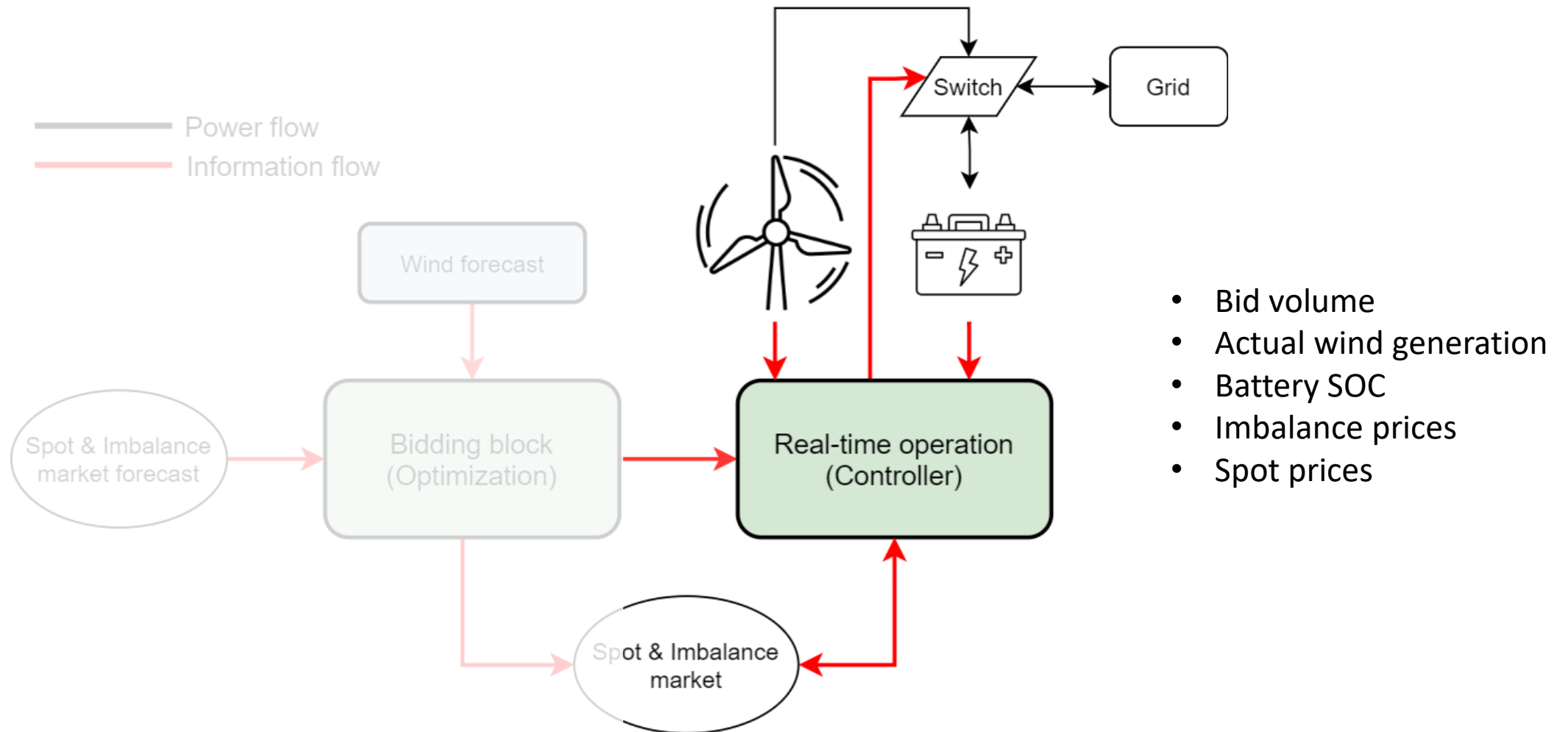
$$\max_x f(x) = \underbrace{(x_{up} + x_d)} \cdot 24 \cdot \underline{\lambda_{cap}} + \sum_{t=1}^{96} \left( \underbrace{x_{up}} \cdot \underline{\beta_{up}(t)} - \underbrace{x_d} \cdot \underline{\beta_d(t)} \right) \cdot (1/4) \cdot \underline{\lambda_{imb}(t)}$$

Design variables

Constraints

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

# Application 1: Arbitrage (Real-time)

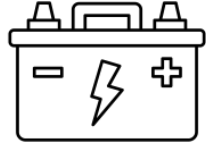
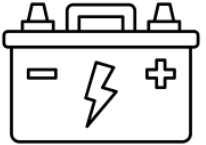


# Application 2: Ancillary services (Real-time)

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

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

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

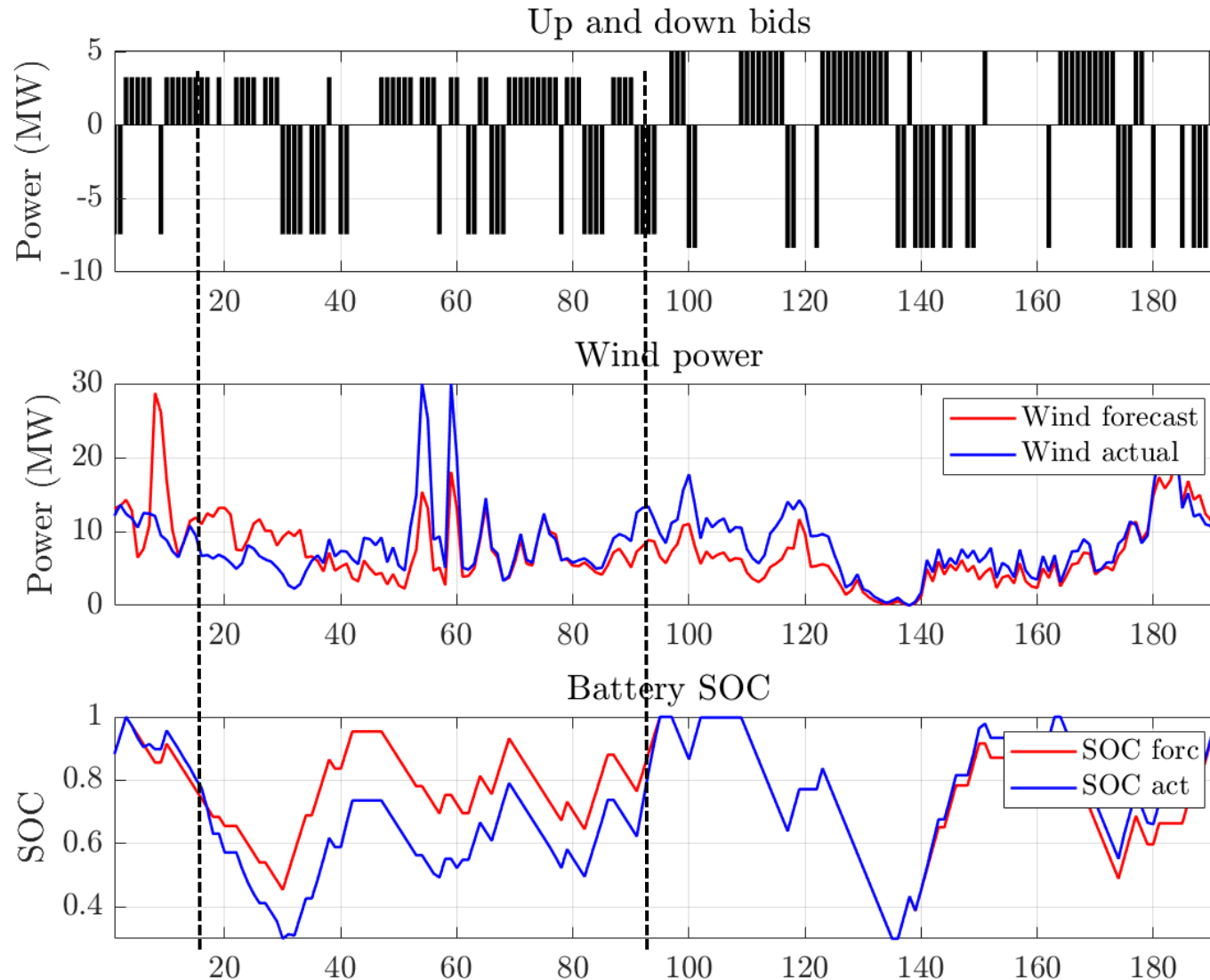
	$P_{diff} < 0$	$P_{diff} > 0$
$\delta > 0$	Discharge* 	Sell to imbalance market
$\delta < 0$	Buy from imbalance market	Charge* 



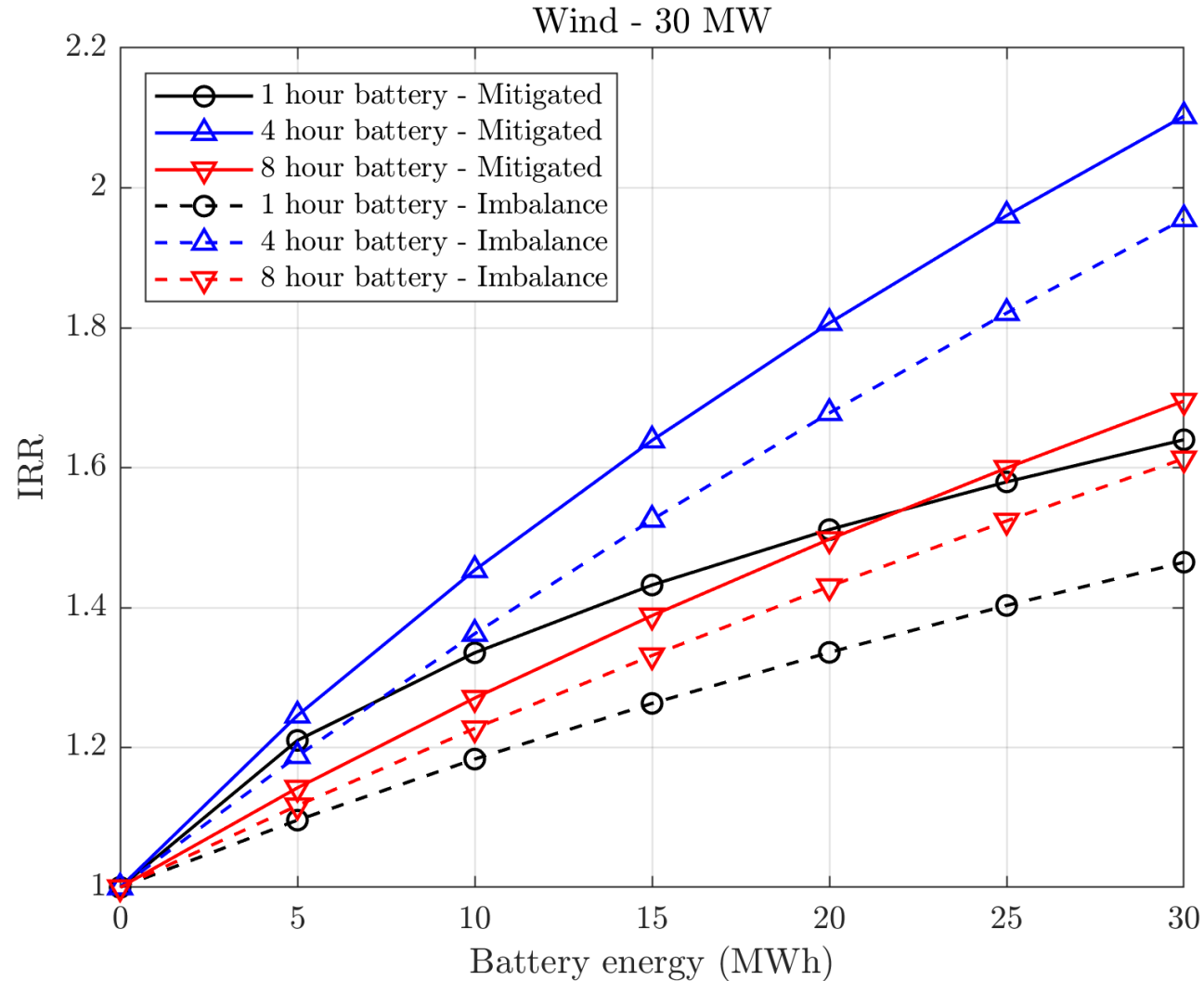
# Application 2: Ancillary services (Illustration)

15<sup>th</sup> time stamp

92<sup>nd</sup> time stamp



# Application 2: Ancillary services (Economics)



# *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.'*