Energy Storage Beyond Arbitrage: Harnessing the Excess Energy of Wind Power Plants

Fabian Moisl

moisl@eeg.tuwien.ac.at

Projekt LEAFS

- LEAFS: Integration of Loads and Electric Storage Systems into advanced Flexibility Schemes for LV Networks
- Laufzeit: November 2015 – Oktober 2018
- Rahmen: 1. Ausschreibung – Energieforschung (FFG)
- Geldgeber: Klima- und Energiefonds

- 3 Modellregionen:
  - Eberstalzell (Netz Oberösterreich)
  - Köstendorf (Salzburg Netz)
  - Heimschuh (Energienetze Steiermark)

- Projektpartner:

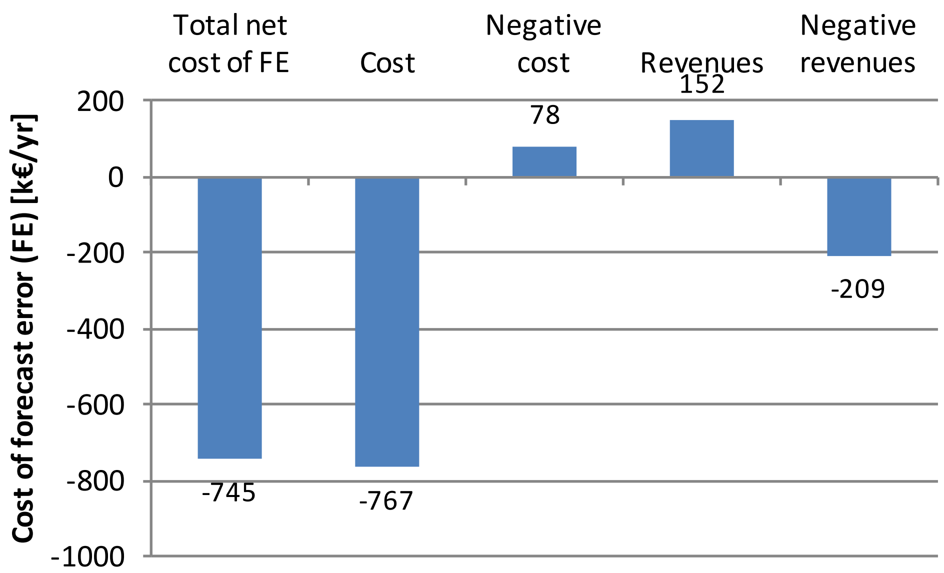
Motivation

- Untersuchte Betriebsstrategien für Batteriespeicher (BESS) in Verbindung mit Windparks (WP)
  - Reduktion der Prognosefehler des WP
  - Bereitstellung von Sekundärregelleistung (negativ)
  - Überschusserzeugung des WP zeitlich verschieben
  - Multimodaler Speichereinsatz
- Dazu: zweistufiges lineares Optimierungsmodell
- Kosten-Nutzen Analyse (Barwertmethode)

Motivation

Zusammensetzung der Kosten für Prognosefehler (FE)

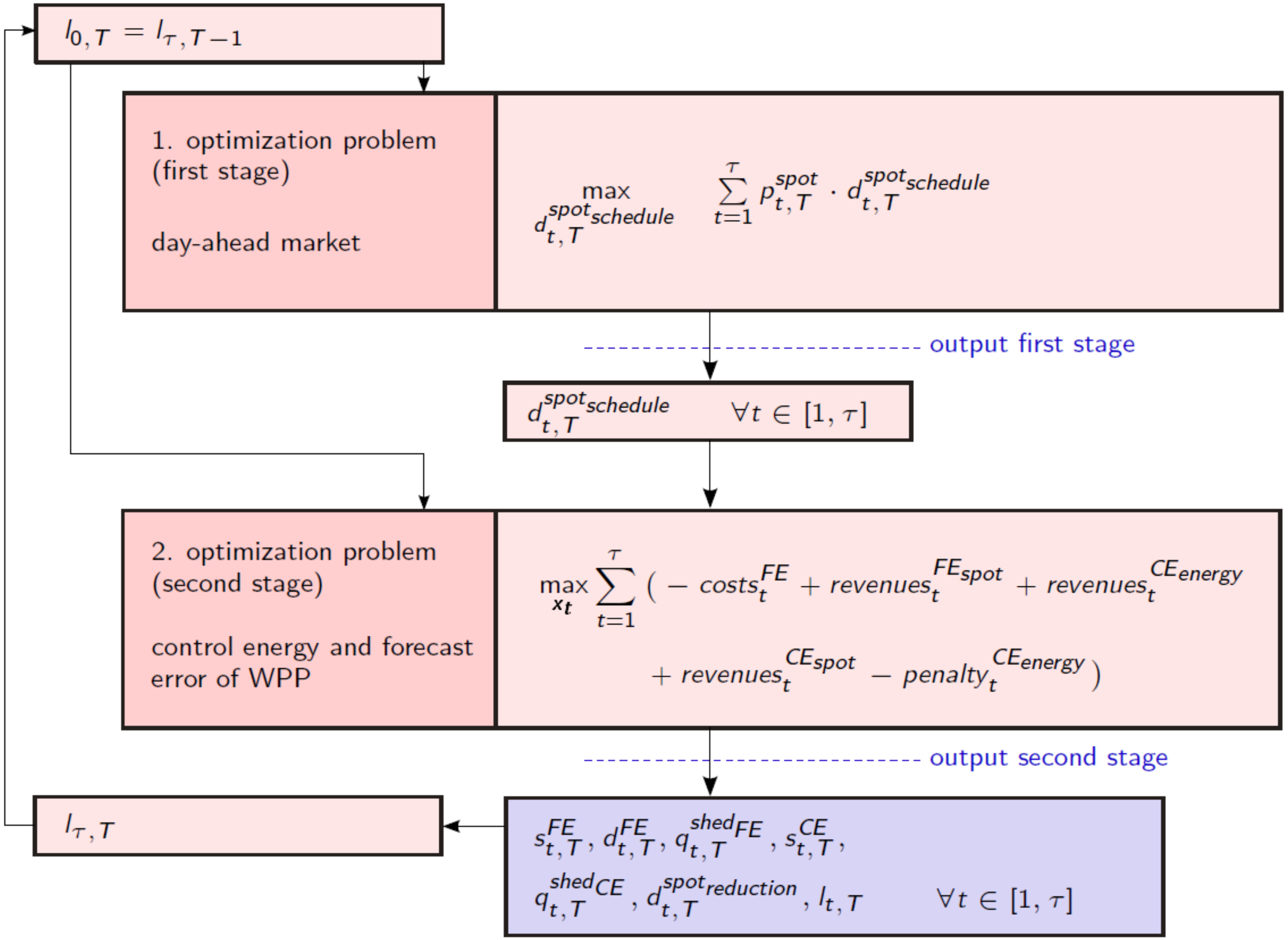
$$total\_net\_cost^{FE} = \sum_t p_t^{balance} \cdot FE_t$$



Windpark mit 20 MW installierter Leistung

$p_t^{balance}$	Ausgleichsenergiepreis [€/MWh]
FE_t	Prognosefehler des Windparks [MWh]

Methode – Lineares Optimierungsmodell



Methode – Modellparameter

Table 1: Operational and economic parameters of lithium-ion battery system

Symbol	Parameter	Unit	Reference Case / [Range]
χ^{BESS}	storage capacity of BESS	MWh	1
$\chi^{BESS}/\kappa^{BESS}$	Hours of energy storage at rated power capacity	h	1
η_{in}^{BESS}	storage charging efficiency	1	0.9
η_{out}^{BESS}	storage discharging efficiency	1	0.9
$cycles_{total}^{BESS}$	Life cycles of BESS	1	7000 / [1000 - 10 000][a]
TPC^{BESS}	Total plant cost of BESS	k€/MWh	1100 / [1046 - 1603][b]
$OPEX^{BESS}$	Operational expenditures of BESS	k€/MW-yr	5 / [4.7 - 6.9][b]

[a] Chen et al., 2009
[b] Akhil et al., 2013

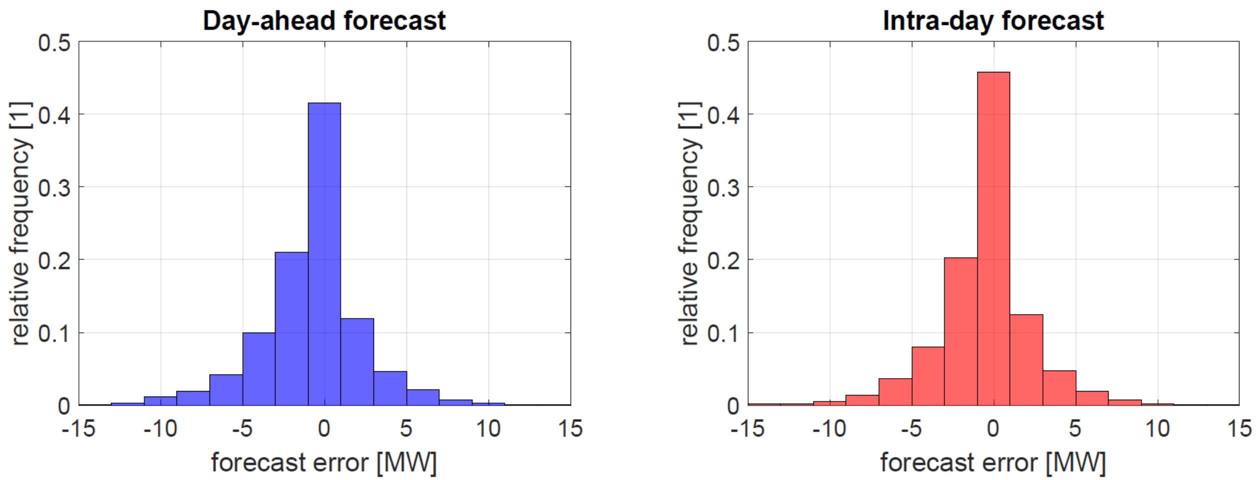
Table 1: Further parameters of wind-storage system assessment.

Symbol	Parameter	Unit	Reference Case / [Range]
-	Installed capacity of WPP	MW	20
P^{CE}	Control reserve power tendered by the wind-storage system	MW	1
V^{CE}	Penalty factor for violation of	1	3
v^{CE}	Fixed rate for collateralization CE request	%	30
τ	Number of quarter hours per time period T	1	96 / [24 - 96]
i	Interest rate	%	10

Ergebnisse – Windpark

Table 1: Assessment of 20 MW wind power plant.

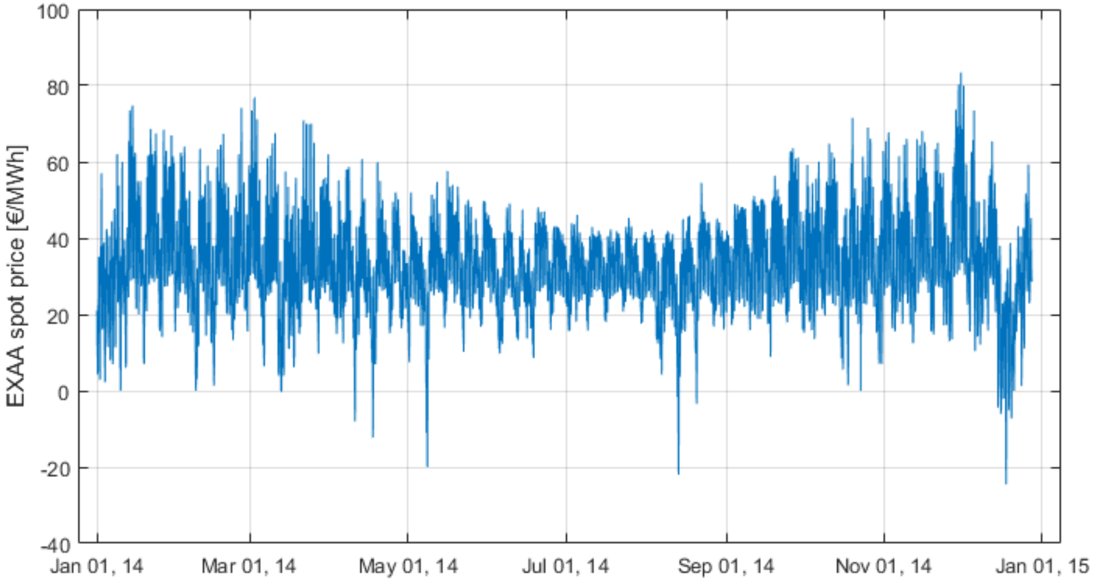
Scheduled yearly generation [GWh]	Actual yearly generation [GWh]	Full-load hours [h/yr]	Revenues day-ahead [k€/yr]	Total cost of forecast errors (day-ahead forecast) [k€/yr]	Total cost of forecast errors (intraday forecast) [k€/yr]
50.6	43.8	2188	1615	-745	-515



(a) Day-ahead forecast (b) Intraday forecast

Figure 2.1: Histograms of forecast errors (interval wigth: 2MW).

Ergebnisse – Arbitrage-only



Source: http://www.exaa.at/de/marktdaten/historische-daten (visited on 10.12.5015)

Table 1: Net present value (NPV) of battery energy storage system (BESS) when employed in arbitrage-only operational mode ($\chi^{BESS} = 1MWh$)

Total net revenues of BESS employment [k€/yr]	Exp. lifetime of BESS[a] [years]	PV of revenues [k€]	PV of $OPEX^{BESS}$ [k€]	PV of TPC^{BESS} [k€]	NPV of BESS [k€]
8.7	11.6	58.2	-33.5	-1100	-1075

[a]Resulting from 603 full-cycle equivalents per year

TPC total plant cost

Ergebnisse – Minimiere Prognosefehler

Table 1: WPP forecast error cost in 2014 under variable storage capacity χ^{BESS} ($\chi^{BESS}/\kappa^{BESS} = 1h$).

χ^{BESS} [MWh]	Total net cost of FE [k€]	$FE < 0$ lack of energy: Cost [k€]	$FE < 0$ lack of energy: Negative cost [k€]	$FE > 0$ surplus of energy: Revenues [k€]	$FE > 0$ surplus of energy: Negative revenues [k€]
0	-744.8	-766.6	78.2	152.3	-208.7
1	-732.5	-737.7	71.7	125.9	-192.4
difference	12.3	28.7	-6.5	-26.3	16.4

Table 1: Net present value of BESS when employed in minimum forecast error operationaol mode ($\chi^{BESS} = 1MWh$, forecast quality: day-ahead).

Total net revenues of BESS employment [k€/yr]	Exp. lifetime of BESS[a] [years]	PV of revenues [k€]	PV of $OPEX^{BESS}$ [k€]	PV of TPC^{BESS} [k€]	NPV of BESS [k€]
12.3	10.3	77.0	-31.3	-1100	-1054

[a]Resulting from 679.3 full-cycle equivalents

TPC total plant cost

Ergebnisse – Multimodaler Speichereinsatz

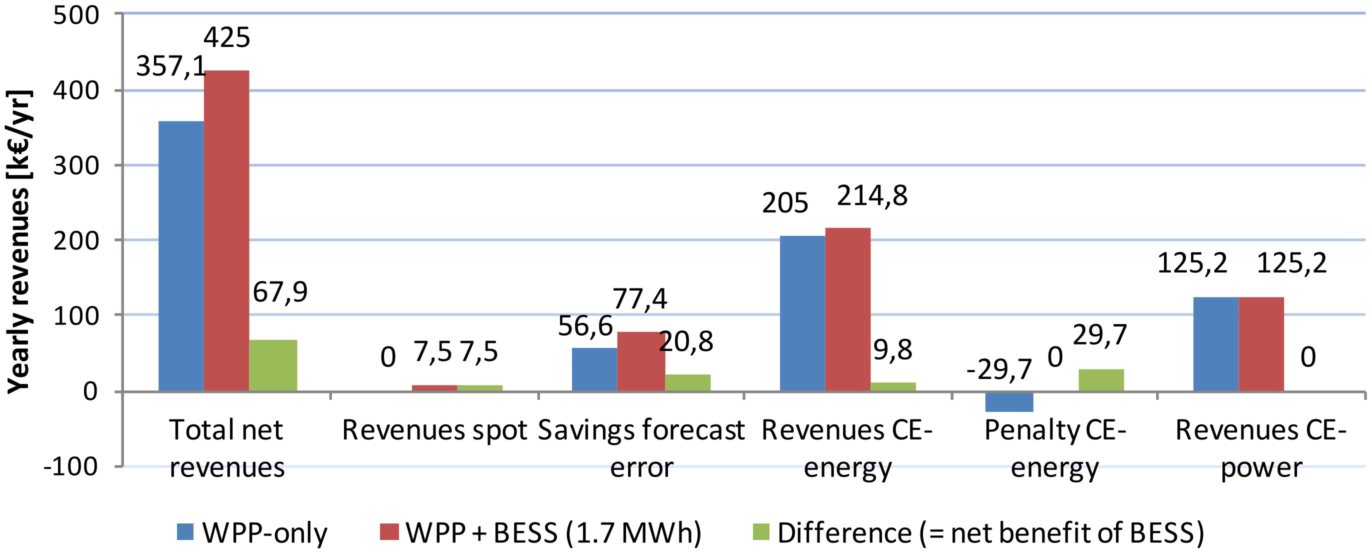
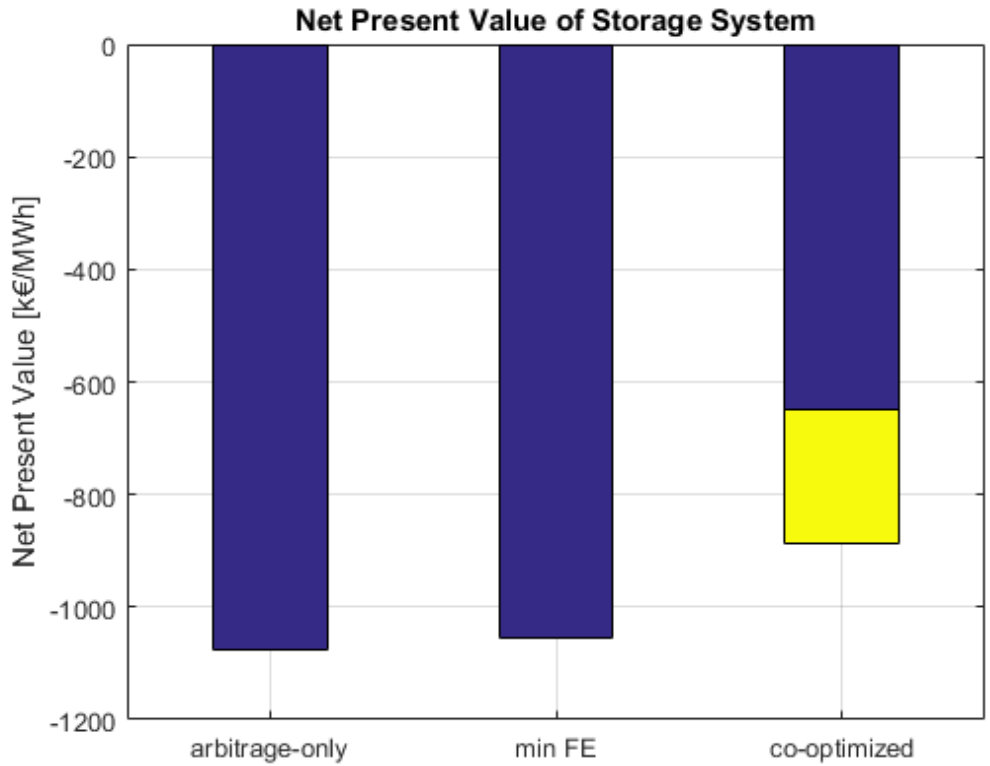


Table 1: Present value of net revenues due to co-optimized employment of the storage system ($\chi^{BESS} = 1.7MWh$, $P^{CE} = 1MW$).

Collateralization of control energy	Total net revenues of BESS employment [k€/yr]	Expected lifetime of BESS[a] [years]	PV of revenues [k€]	PV of $OPEX^{BESS}$ [k€]	PV of TPC^{BESS} [k€]	NPV of BESS [k€]
Penalty factor	67.9	9.1	393.1	-28.9	-1870	-1506
Fixed rate	137.2	9.1	794.1	-28.9	-1870	-1104

[a]Resulting from 762.5 full-cycle equivalents per year.

Ergebnisse – Vergleich der Betriebsstrategien



Schlussfolgerungen und Ausblick

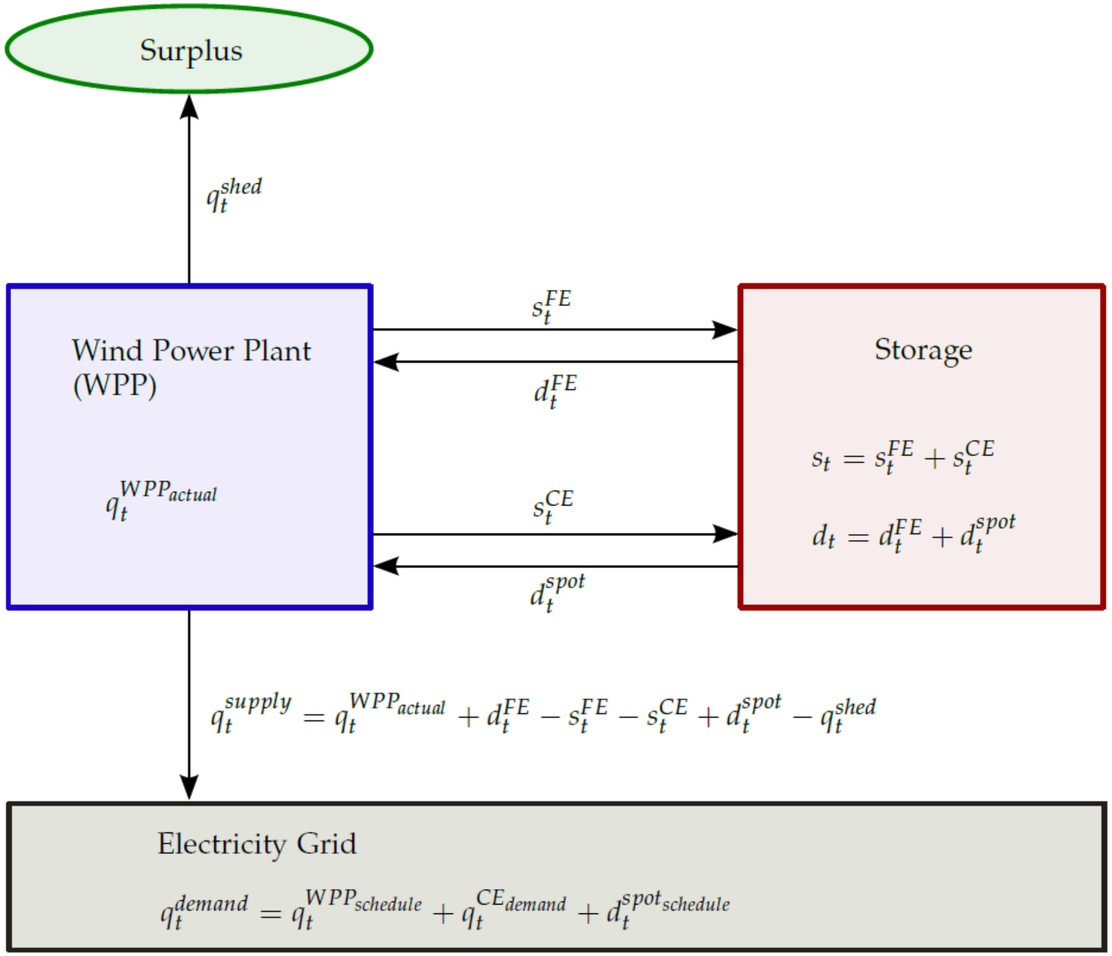
- Keine der betrachteten Einsatzstrategien für Batteriespeicher rechtfertigt die Investitionskosten (Barwerte immer negativ)
- Speicherkosten müssten um 60-80% sinken, damit Barwert im multimodalen Betrieb positiv wird
- Durch Abregelung von Windturbinen bei positivem Prognosefehler könnten Ausgleichsenergiekosen in der Höhe von einigen zehntausend Euro eingespart werden
- Ausblick: Erlöse können weiter gesteigert werden, wenn Speicher für positive und negative Regelleistungsbereitstellung verwendet werden

Literaturverzeichnis

- Akhil, Abbas A. et al. (2013). DOE/EPRI *2013* electricity storage handbook in collaboration with NRECA. Sandia National Laboratories Albuquerque, NM,USA. url: http://www.emnrd.state.nm.us/ECMD/RenewableEnergy/documents/SNL-ElectricityStorageHandbook2013.pdf (visited on 12/10/2015)

- Chen, Haisheng et al. (2009). "Progress in electrical energy storage system: A critical review." In: Progress in Natural Science 19.3, pp. 291–312. issn: 10020071. doi: 10.1016/j.pnsc.2008.07.014. url: http://linkinghub.elsevier.com/retrieve/pii/S100200710800381X (visited on 12/09/2015)

Anhang - Methode



Anhang - Methode – 1. Stufe des Opt.modells

Maximiere Erlöse am day-ahead Markt

$$\max_{d_{t,T}^{spot_{schedule}}} \sum_{t=1}^{\tau} p_{t,T}^{spot} \cdot d_{t,T}^{spot_{schedule}} \tag{1}$$

s.t.

$$d_{t,T}^{spot_{schedule}} \geq 0 \qquad \forall t \in [1,\tau] \tag{2}$$

$$d_{t,T}^{spot_{schedule}} \leq \kappa^{BESS} \cdot 1/4 \qquad \forall t \in [1,\tau] \tag{3}$$

$$l_{t,T} \geq 0 \qquad \forall t \in [1,\tau] \tag{4}$$

$$l_{0,T} = l_{\tau,T-1} \tag{5}$$

$$l_{t-1,T} - (d_{t,T}^{spot_{schedule}} / \eta_{out}^{BESS}) = l_{t,T} \tag{6}$$

$p_{t,T}^{spot}$	day-ahead strompreis [€/MWh]
$d_{t,T}^{spot_{schedule}}$	geplanter day-ahead Speichereinsatz (discharge) [MWh]
κ^{BESS}	Leistung des Speichers [MW]
$l_{t,T}$	Speicherfuellstand [MWh]

Anhang - Methode – 2. Stufe des Opt.modells

Maximiere die erwarteten Gesamterlöse

$$\max_{\boldsymbol{x_t}} \sum_{t=1}^{\tau} \Big(-p^{balance}(|FE_t| - d_t^{FE} - s_t^{FE} - q_t^{shed_{FE}}) + p^{spot} \cdot s_t^{FE} \cdot \eta^{BESS}$$

$$+ p_t^{CE_{MWh}}(s_t^{CE} + q_t^{shed_{CE}} + d_t^{spot_{reduction}})$$

$$+ s_t^{CE} \cdot \eta^{BESS} \cdot p^{spot} + d_t^{spot_{reduction}} \cdot p^{spot}$$

$$- V^{CE} \cdot p_t^{CE_{MWh}} [\Theta_t^{CE} \cdot P^{CE} \frac{1}{4} - (s_t^{CE} + q_t^{shed_{CE}} + d_t^{spot_{reduction}})] \Big)$$

$$\boldsymbol{x_t} = [d_t^{FE}, s_t^{FE}, q_t^{shed_{FE}}, s_t^{CE}, d_t^{spot_{reduction}}, q_t^{shed_{CE}}].$$

s_t	store energy [MWh]
d_t	discharge energy [MWh]
FE	Prognosefehler (forecast error)
CE	Regelenergie (control energy)

Anhang - Methode – Erlöse

Erlöse aus Leistungspreis für Regelenergie:

$$revenues^{CE_{power}} = p^{CE_{MW}} \cdot P^{CE} \cdot 8760h$$

WP muss Regelenergie liefern, wenn Regelenergiebedarf > $q_{threshold}$ (Abrufwahrscheinlichkeit 10%)

$$\Theta_t^{CE} = \begin{cases} 1 & \text{if } q_t^{CE} > q_{threshold}^{CE} \\ 0 & \text{otherwise} \end{cases}$$

Table 1: Historical market data of the year 2014

Symbol	Parameter	Unit	Value
p^{spot}	average spot market price	€/MWh	32.80
$p^{CE_{MW}}$	average price for control power	€/MW·h	14.29
$p^{balance}$	average cost of balancing energy	€/MWh	39.59
$q^{CE}_{threshold}$	threshold for negative aFRR	MWh	36.68