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Optimized Operation of PV-Diesel Hybrid Systems

How much storage is useful?

PV DAYS 2017 and 10 years Fraunhofer CSP | October 24-25, Halle (Saale)

Prof. Dr.-Ing. Antonio Notholt – Control engineering & innovative energy systems

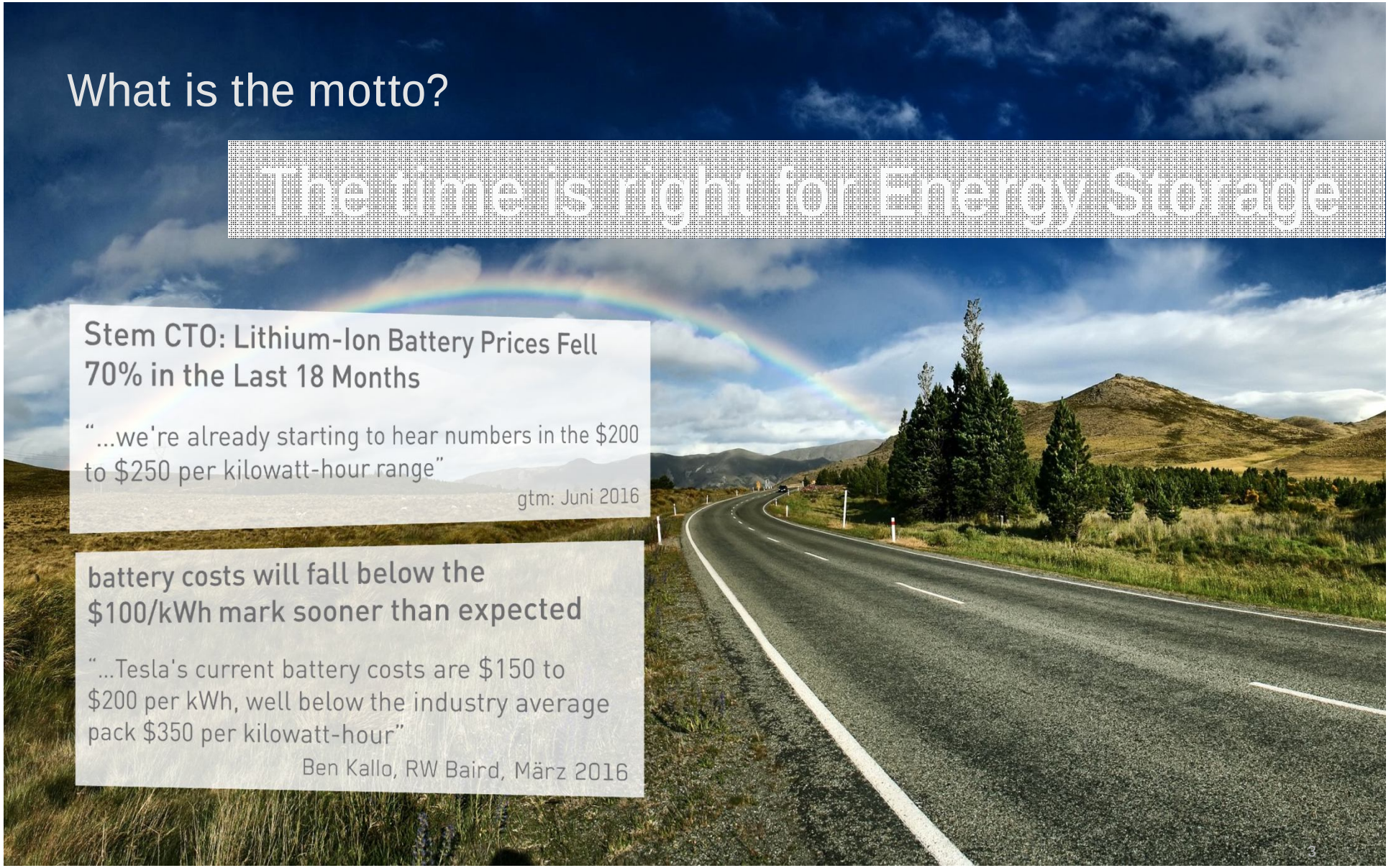
Industrial Off-Grid hybrid with energy storage systems are today already economically competitive against conventional generation

But how much storage is really necessary?

- Return of Investment as little as 5 years
- Large renewable energy (solar) fraction is possible
- Industrial & critical applications (e.g. mines) already trust it

What is the motto?

The time is right for Energy Storage



Classification of hybrid systems

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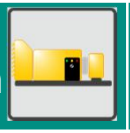
Type	Genset operation 	Photovoltaic generator 	Storage size 	Controller	Fuel savings
0	24/7	No control necesary	N/A	N/A	+ (SF < 5%)
1	24/7	Controllable (limit)	N/A	PV (limiting)	++ (SF < 15%)
2a	24/7	Controllable (limit)	Small (Power application)	PV & Storage (ramp rate & reserve)	+++ (SF < 25%)
2b	24/7	Controllable (limit)	Medium (power/energy application)	PV & Storage (Ramp rate & peak shaving)	++++ (SF > 25%)
3	On demand	Controllable (limit)	Large (with grid forming capabilities)	PV, Storage & Diesel	+++++ (SF > 50%)

Based on the classification per Fraunhofer ISE (Rogalla, et al. 03/2017 Bad Staffelstein)

Motivation

Why do we need storage at all?

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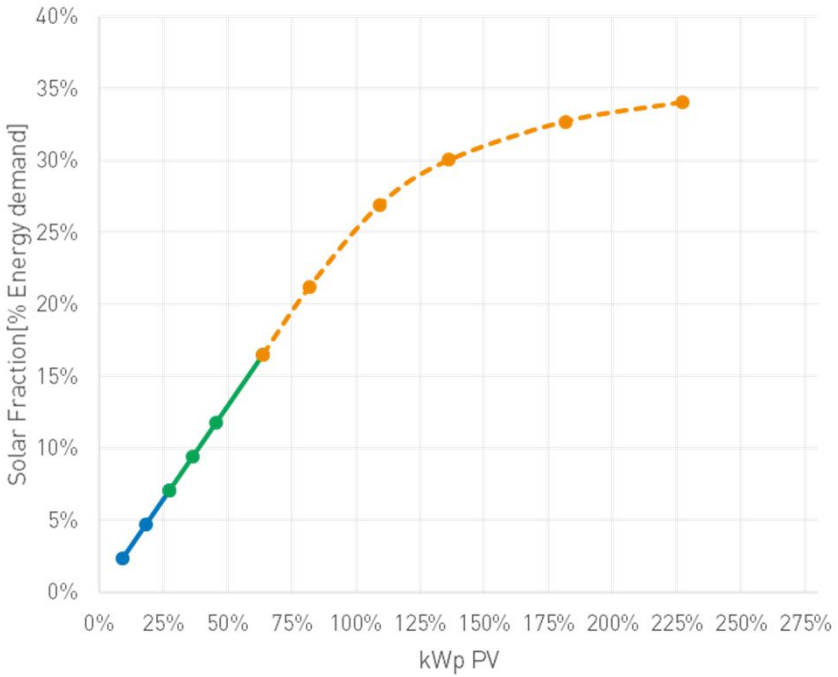
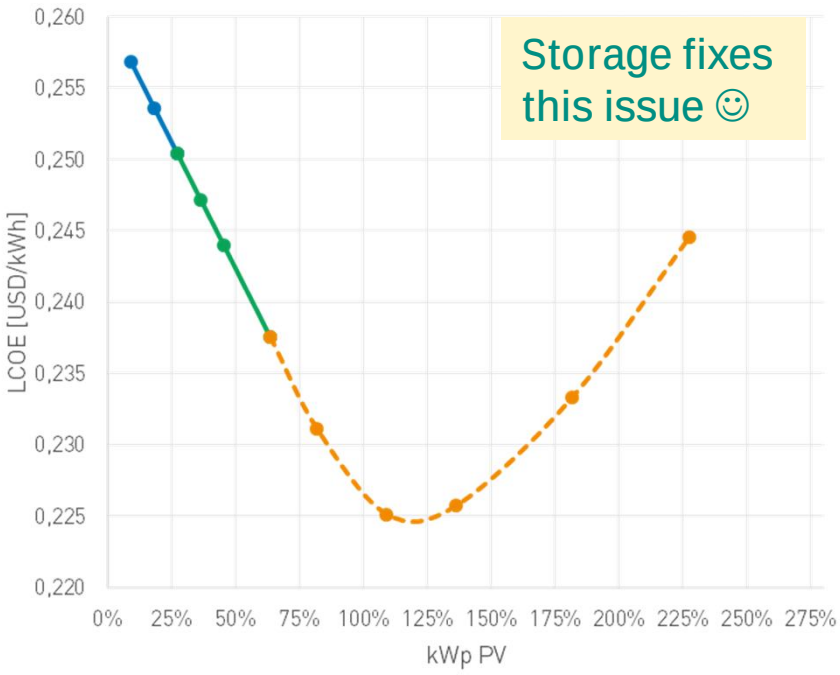
> PV-Diesel hybrids are economically feasible

> But the optimum is usually not reached due to PV's lack of dispatchability ☹





Storage fixes this issue ☺

Example calculation HS in Bolivia, Load 165MWh/dy, CAPEX PV: 1 250USD/kWp, CAPEX Battery: 1000USD/kWh, OPEX: 10% CAPEX/a, Diesel:production costs 0,26 USD/kWh (~1USD/l)

How much battery is useful (power applications)?

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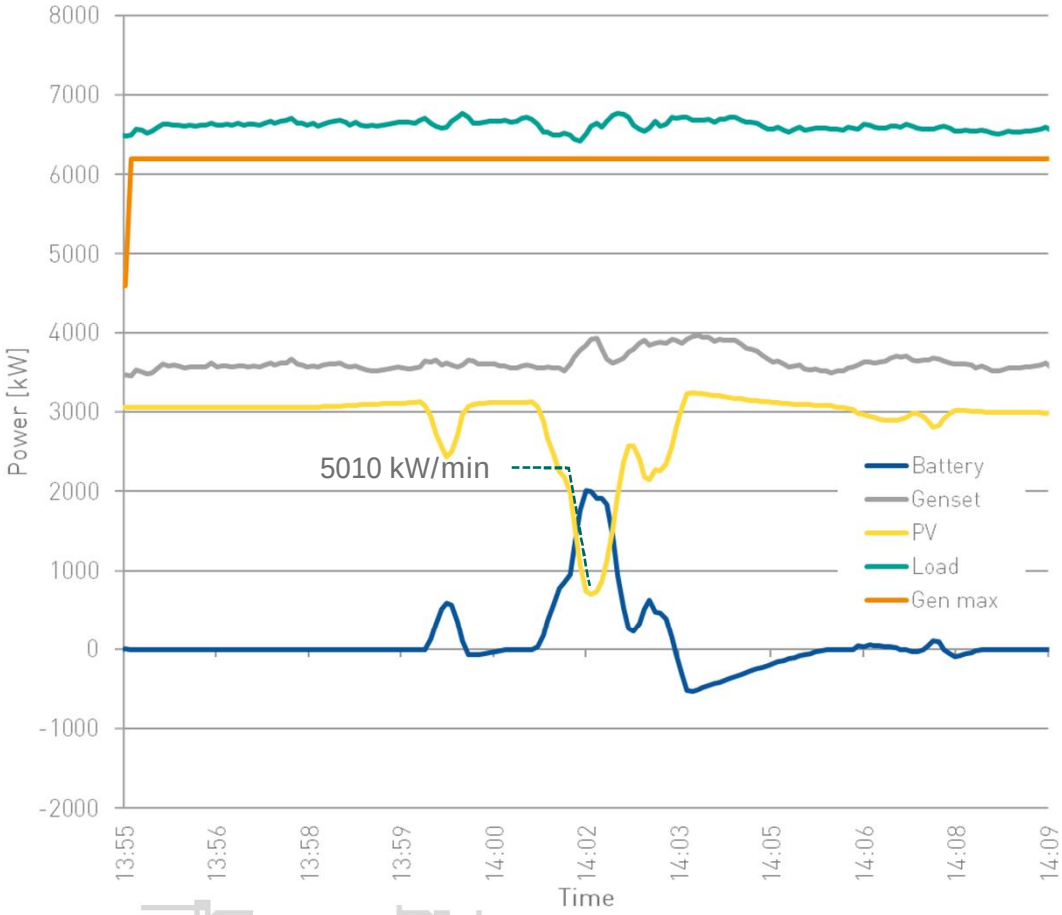
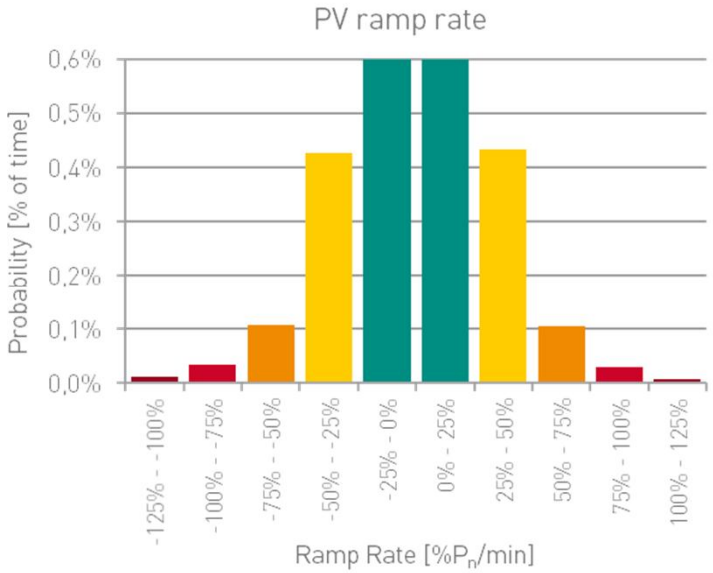


A good approximation for battery sizing for power applications

$$P_{bat} \cong \frac{1}{2} P_{pk}$$

With a discharge rate of 2C



Field test

Cobija, BO – Impressions

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22.000 Modules

20 Strings

24/7 Operation

10.500.000 l/year*

* Average consumption 0,26 l/kWh

Use of the energy storage (Ramp rate & reserve)

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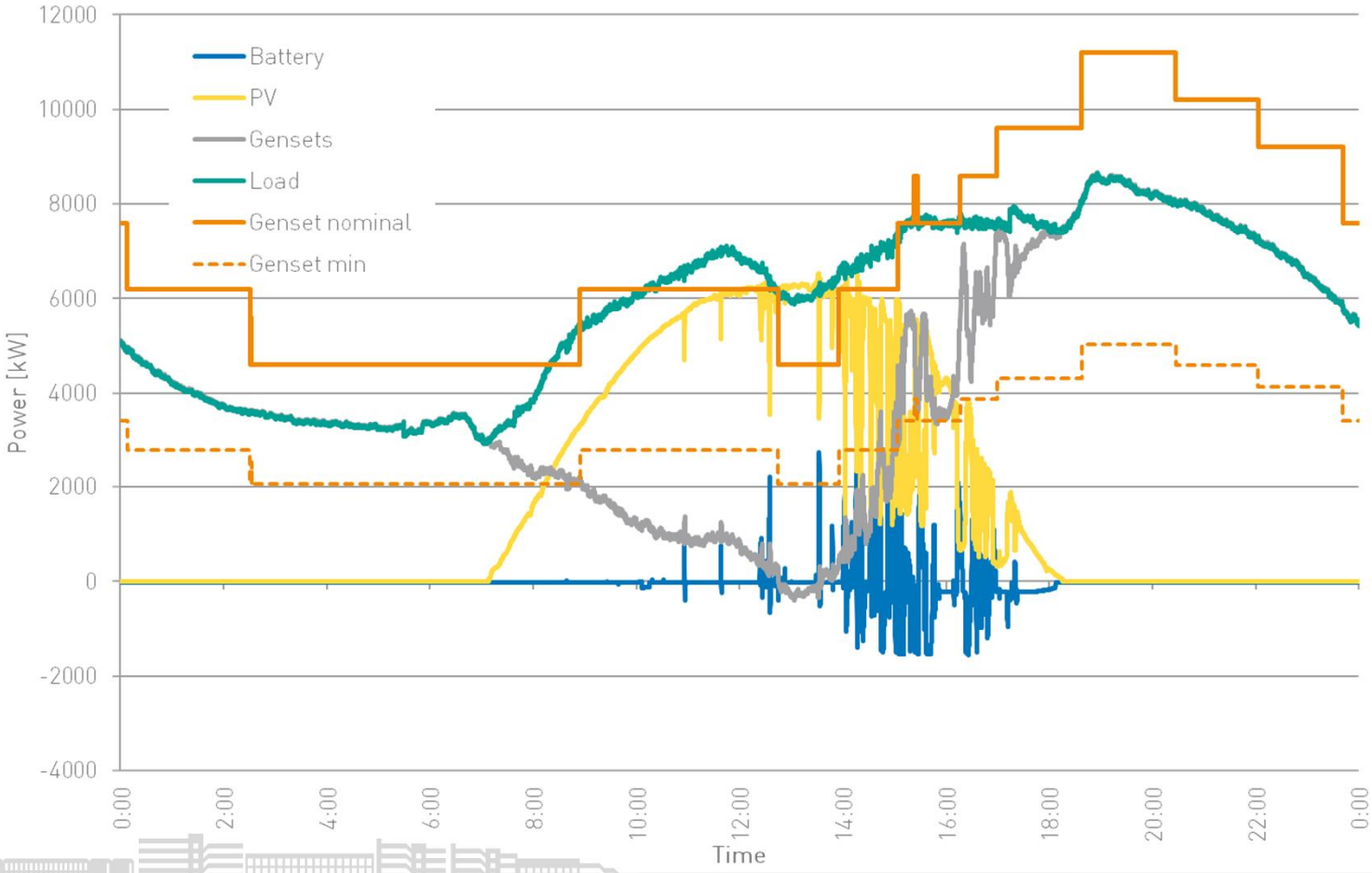

Performance

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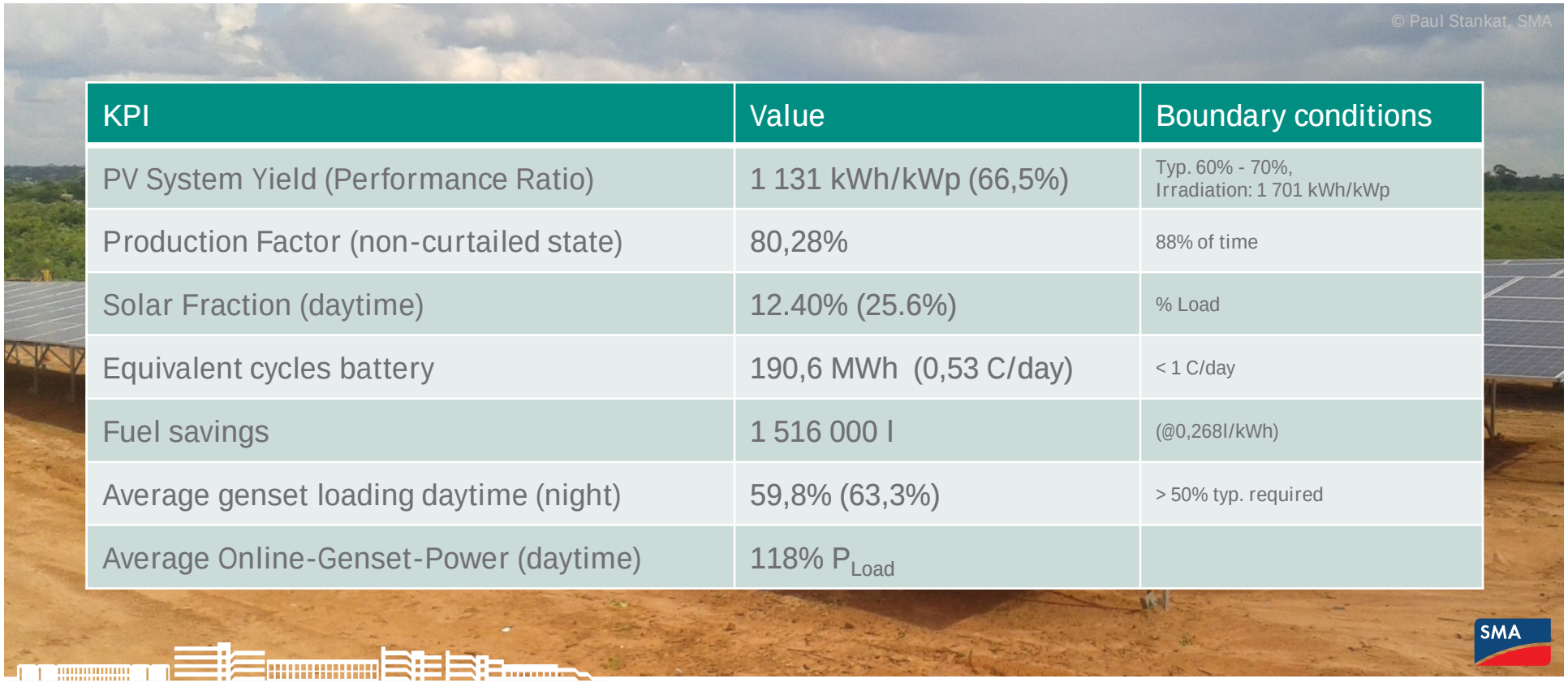
June 2015 to June 2016



KPI	Value	Boundary conditions
PV System Yield (Performance Ratio)	1 131 kWh/kWp (66,5%)	Typ. 60% - 70%, Irradiation: 1 701 kWh/kWp
Production Factor (non-curtailed state)	80,28%	88% of time
Solar Fraction (daytime)	12.40% (25.6%)	% Load
Equivalent cycles battery	190,6 MWh (0,53 C/day)	< 1 C/day
Fuel savings	1 516 000 l	(@0,268l/kWh)
Average genset loading daytime (night)	59,8% (63,3%)	> 50% typ. required
Average Online-Genset-Power (daytime)	118% P_{Load}	

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Which type of storage?

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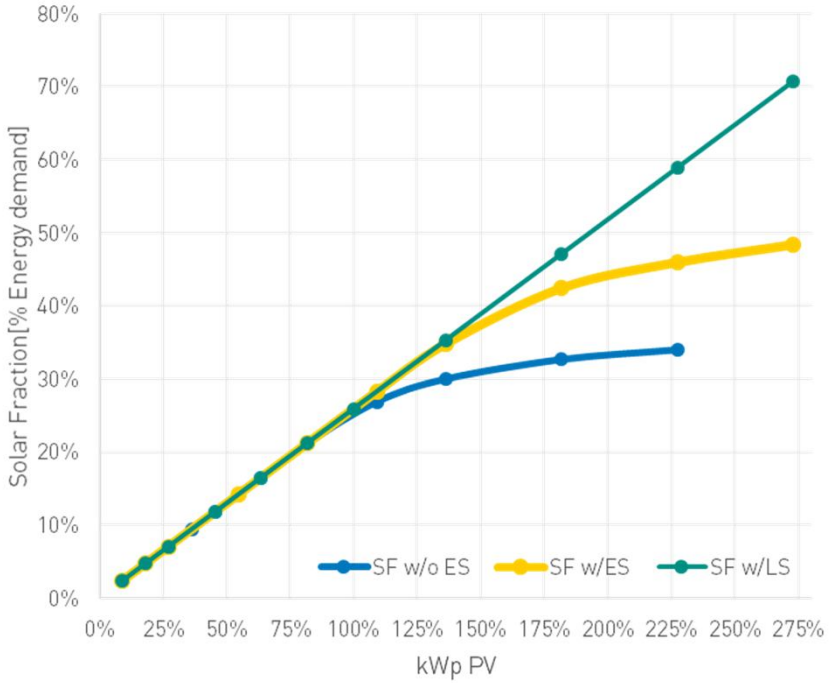
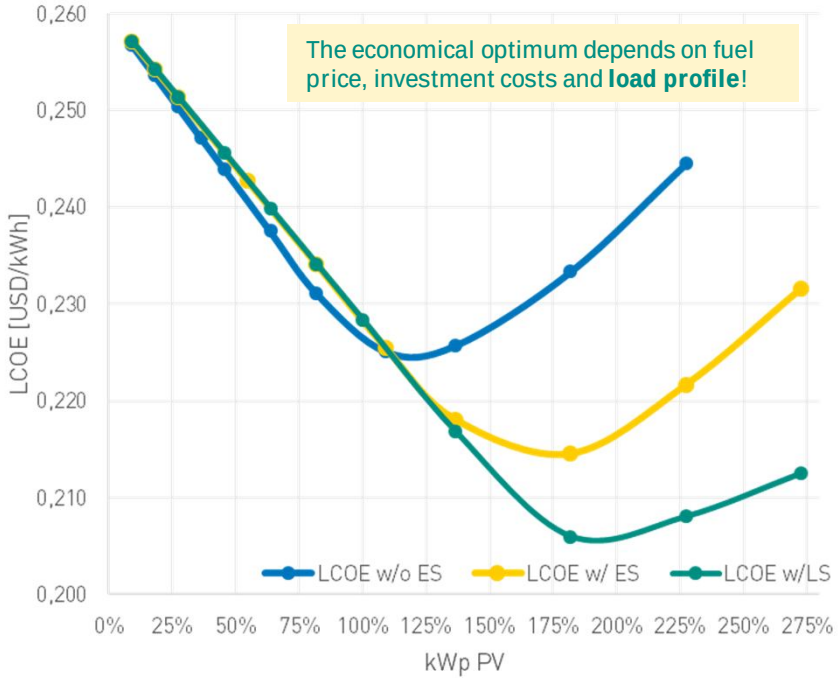
> Power trimmed storage (ES) provides the largeste cost/benefit leverage
> Large storage provides a further optimization point but require large changes in technology and operation





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Storage is no longer the main issue...

> The system becomes inverter-dominated
  > Inertia is only emulated
  > A review of protection schemes is required

> The system must be able to run without gensets
  > Each running genset adds a minimum load and thus may require curtailment
  > A transition between Diesel-on and Diesel-off is a large challenge

> The system shall communicate
  > PV is per se decentalized but to control a large decentralized plant, new communication paradigms are necessary

Showcase Sint Eustatius

First projects with industrial grid-forming inverters

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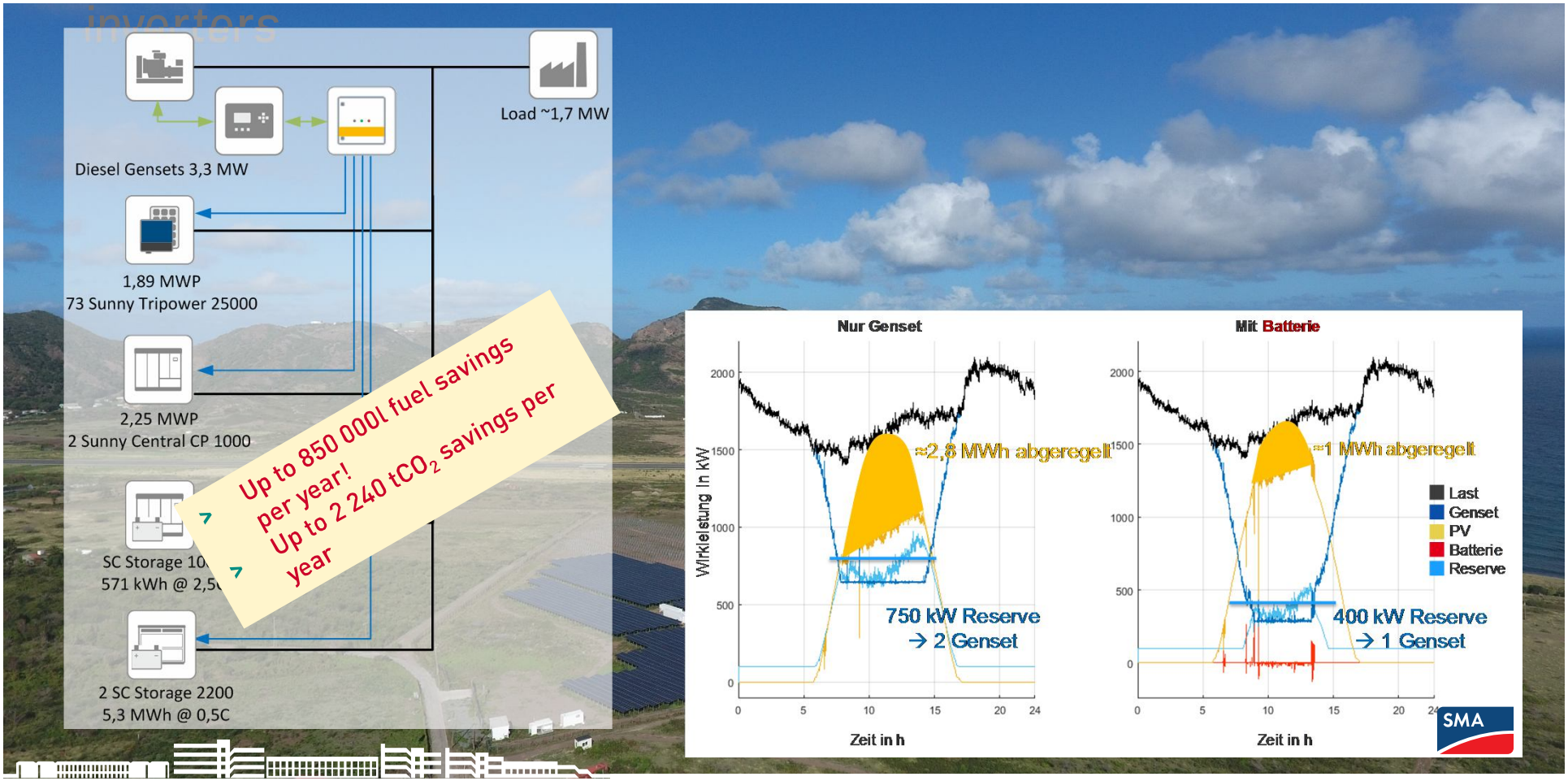
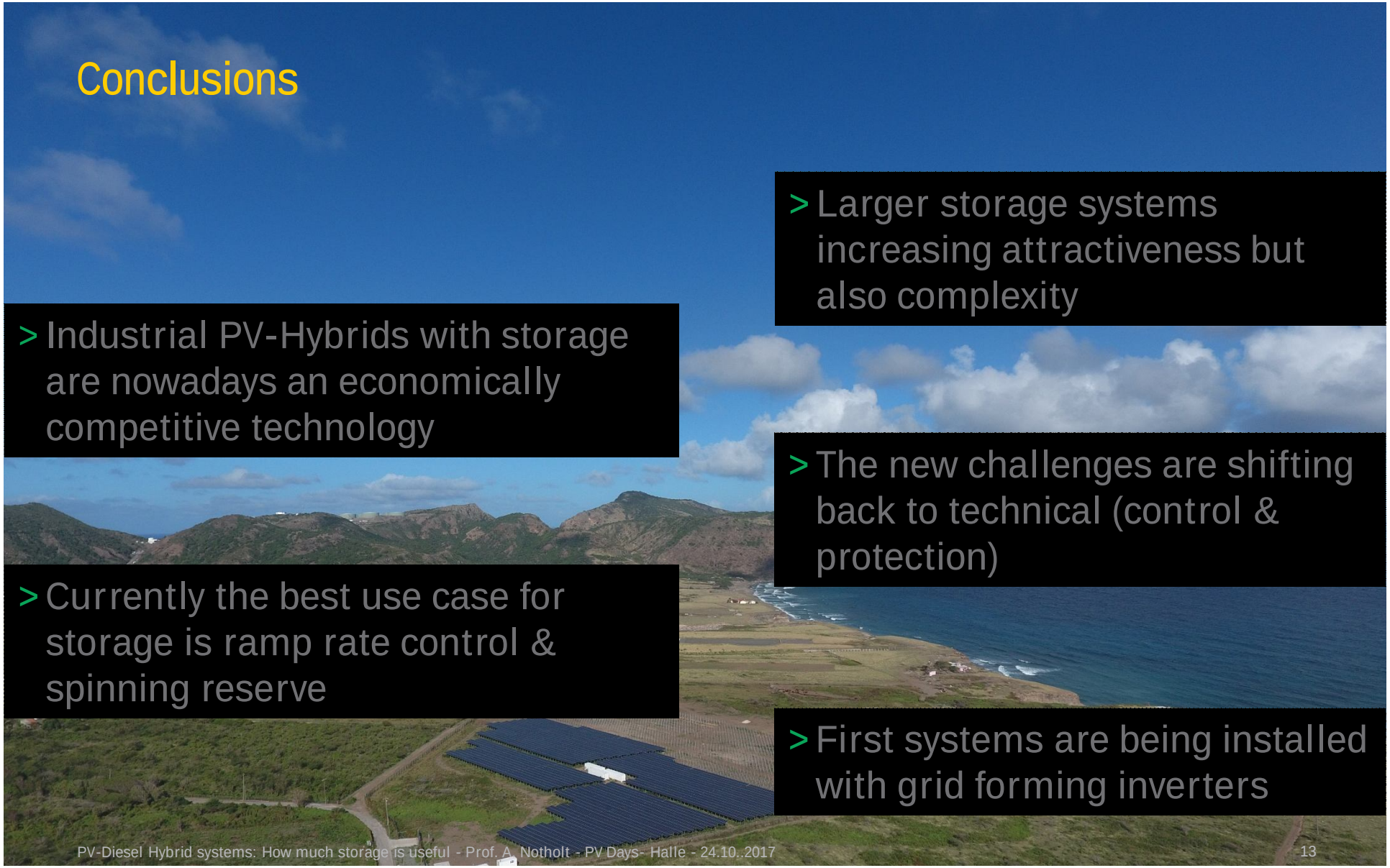


Conclusions



> Industrial PV-Hybrids with storage are nowadays an economically competitive technology

> Larger storage systems increasing attractiveness but also complexity

> The new challenges are shifting back to technical (control & protection)

> Currently the best use case for storage is ramp rate control & spinning reserve

> First systems are being installed with grid forming inverters

Sorry, what was the question?

How much storage is useful?

Application	Proposed size
Spinning reserve	50% P_{pk} minimum 1 genset size, 2C
Ramp rate control	50% P_{pk}, 2C
Energy shifting / economic operation	P large enough to store curtailed power, minimum 50% P_{pk} and capacity enough to store all surplus energy of the average production

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Success Story St. Eustatius

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Abonnement

THEnergy bestätigt hohe Performance einer Photovoltaik-Batterie-Diesel-Hybridanlage von SMA Sun-belt

Das auf der Karibikinsel installierte System soll erweitert werden. Der Energieversorger Stuco will danach zumindest an sonnigen Tagen komplett auf die Dieselgeneratoren verzichten.

6. JULI 2017 SANDRA ENKHARDT

SPEICHER TECHNOLOGIE DEUTSCHLAND ZENTRALAMERIKA UND SÜDAMERIKA

Parameter	Forecast (21.09.2015)	Measurement (28.03.2016-27.03.2017)	Relative values
Total load [MWh]	13 697	13 087	4.5% less
Fuel savings [liter]	822 733	812 887	1.2% less
Rel. fuel savings [l/MWh]	60.1	62.1	3.4% more
Renewable energy fraction [%]	23%	23.89%	3.8% more
Performance ratio of the PV system [%]	82%	>82%	0%
Irradiation [kWh/m²]	2124	2021	4.9% less
Energy produced by PV system [MWh]	3200	3126	2,3% less
Curtailed PV energy [MWh] / [%]		216 / 6.45%	
Battery energy throughput [MWh]	149	148	0.7% less
Diesel generator [MWh]	10 467	10 007	4.4% less
Battery capacity /state of health [kWh] / [%]	547/ 95.6	565 / 98.7	3.2% more

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Source: THEnergy consulting & pv magazine

Off-Grid Hybrids vs. Minigrids

Off-grid Hybrid systems

> Reliable system operation though the use of a system controller is guaranteed
  > Minimum loading of fuel-based gen.
  > Sufficient spinning reserve in system
  > PV curtailment for grid stability

> Aims to the most economic operation
  > Largest fuel savings
  > Largest solar contribution
  > Smallest genset running hours

Grid connected Microgrids

> Microgrid controller assures the balance between generation and consumption
  > Energy management
  > Scheduling of generation and load
  > In island mode the same as hybrid

> Aims to the maximum profit
  > Maximize the use of cheap energy
  > Minimize system losses

Off-grid controllers can help to a new standard of automated grid operation…

Projektziele

Erhöhung des möglichen solaren Deckungsanteils (deutlich über 25%)

Kostengünstiges und erprobtes Baukastensystem für flexible, wirtschaftliche Systemlösungen

Erhebliche Reduktion des Dieseltreibstoffverbrauchs durch Photovoltaik

Erhöhung der Zuverlässigkeit und Robustheit

Conclusions

- Our projects have contributed to the technology developent „made in Germany“ for the export market
- Developed tools and predictions have good quality
- Field tests have shown that an automated system for grid operation is possible
- Storage adds flexibility and helps the efficient system operation
- Projects integating other EE sources are running