Application of Gridforming Inverters in Off-Grid and On-Grid Applications

Presented by Dr. Thorsten Bülo

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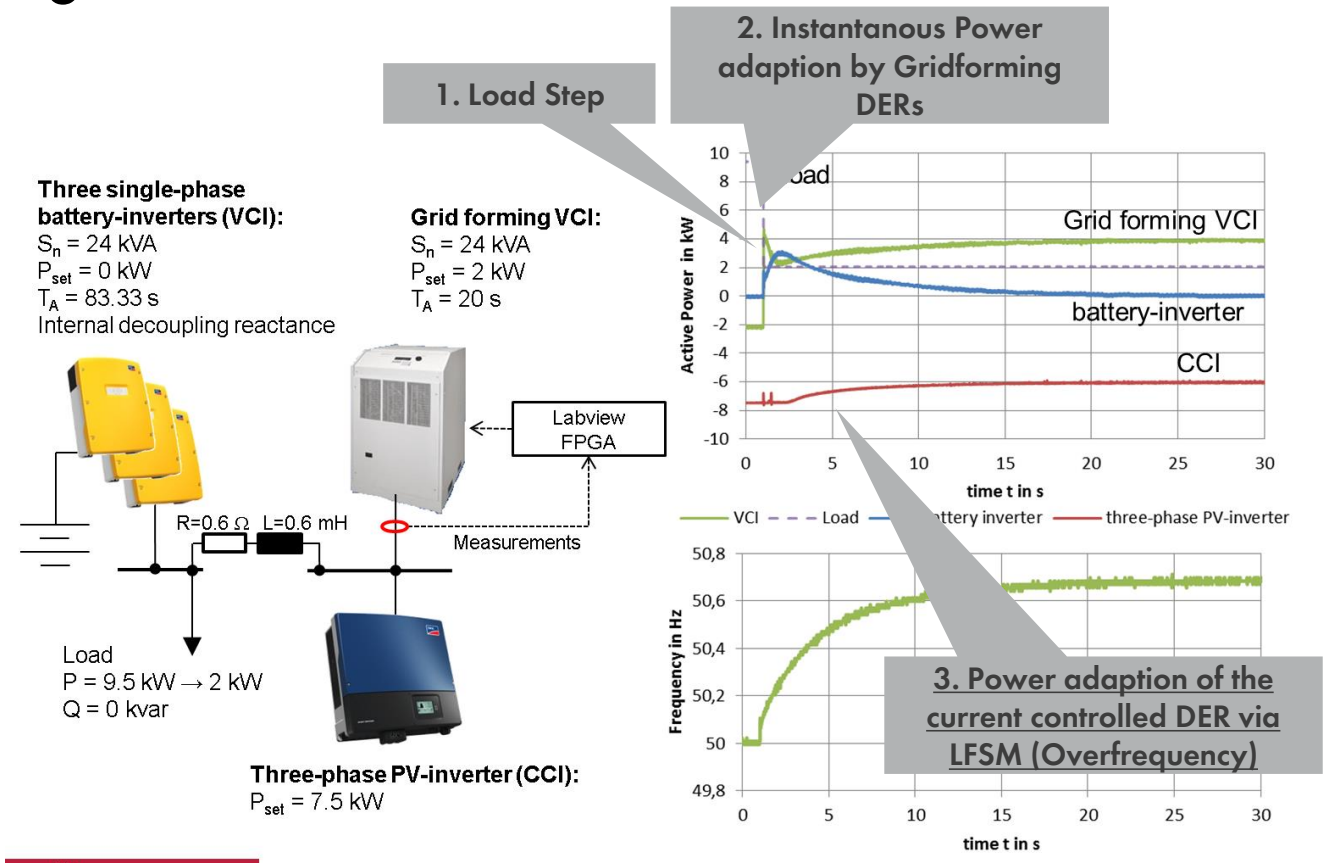
Agenda – Application of Gridforming Inverters

1. **Principle Comparison - Small Scale**
2. **Large Scale PV-/Diesel Hybrid-Systems**
3. **„On-Grid“ Application and Outlook**

Laboratory test of different, parallel operating gridforming converters and grid-supporting PV

Parallel operation of Voltage controlled Inverters: Load step

- Application of f(P) and V(Q) droops
- Load Balancing after transient is determined by control strategy and passive components
- Load is immediately taken over by the gridforming VCI and the Gridfroming battery inverters.
- Frequency is adjusted by the parallel operating Gridforming inverters
- Conventional PV-Inverters adjust their output according to their P(f)-curve (LFSM-O)



Technische Universität Braunschweig

June 28, 2016 | Stefan Laudahn | Substitution of generators by inverters | Page 12

Nach: Laudahn, Bülo, Premm, Seidel, Engel: Substitution of Synchronous Generator Based Instantaneous Frequency Control Utilizing Inverter coupled DER

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Integration of VRE in a Microgrid

Phases of VRE Integration

- Higher shares requires more efforts for integration
- Possible measures to achieve the according phase of Solar Integration in an isolated Microgrid

Compare:
„Status of Power System Transformation“, Dr. Peerapat Vithayasrichareon, IEA 2018, Solar Integration Workshop

Phase	Est. max. Share in power	Measures to achieve stable operation
2	~15%	**Limit Installations** • Using existing flexibility • No measures for operation
3	~50%	**Curtailment** • Limits the input to an allowable share in the power system by active curtailment
4	<80%	**Storage** • Reserve-Power • Must-Run units
5	100%	**Grid-Forming** • Allows switching off all conventional Voltage-Sources • Maximum Penetration

Taken from: O. Schömann et. al: Experiences with large grid-forming Inverters on various Island and Microgrid projects, Hybrid fPower Systems Workshop 2019

Replacing conventional synchronous generation in island grids for up to 100% renewable power & energy supply

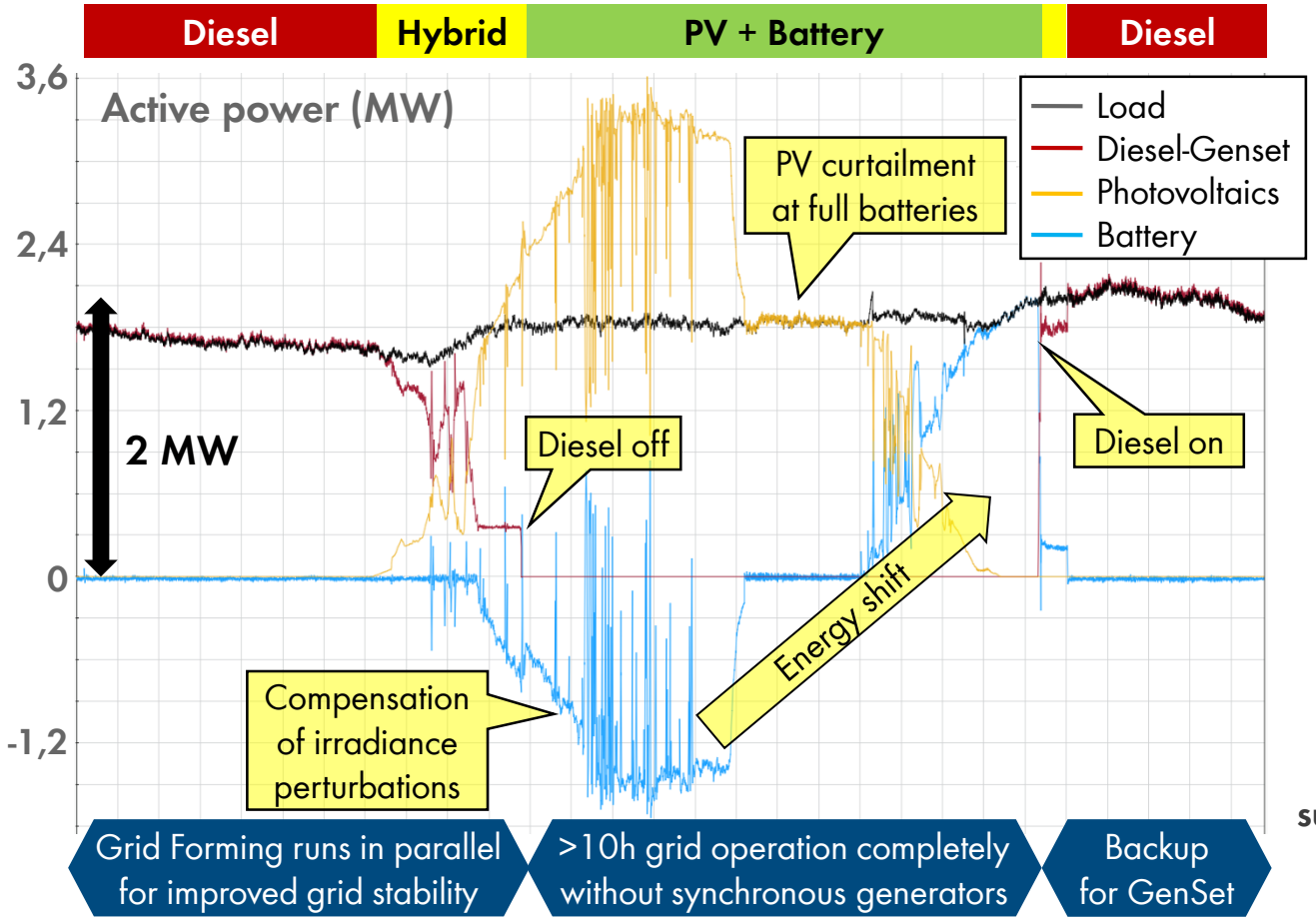
Hybrid System on Caribbean island St.Eustatius[3]:

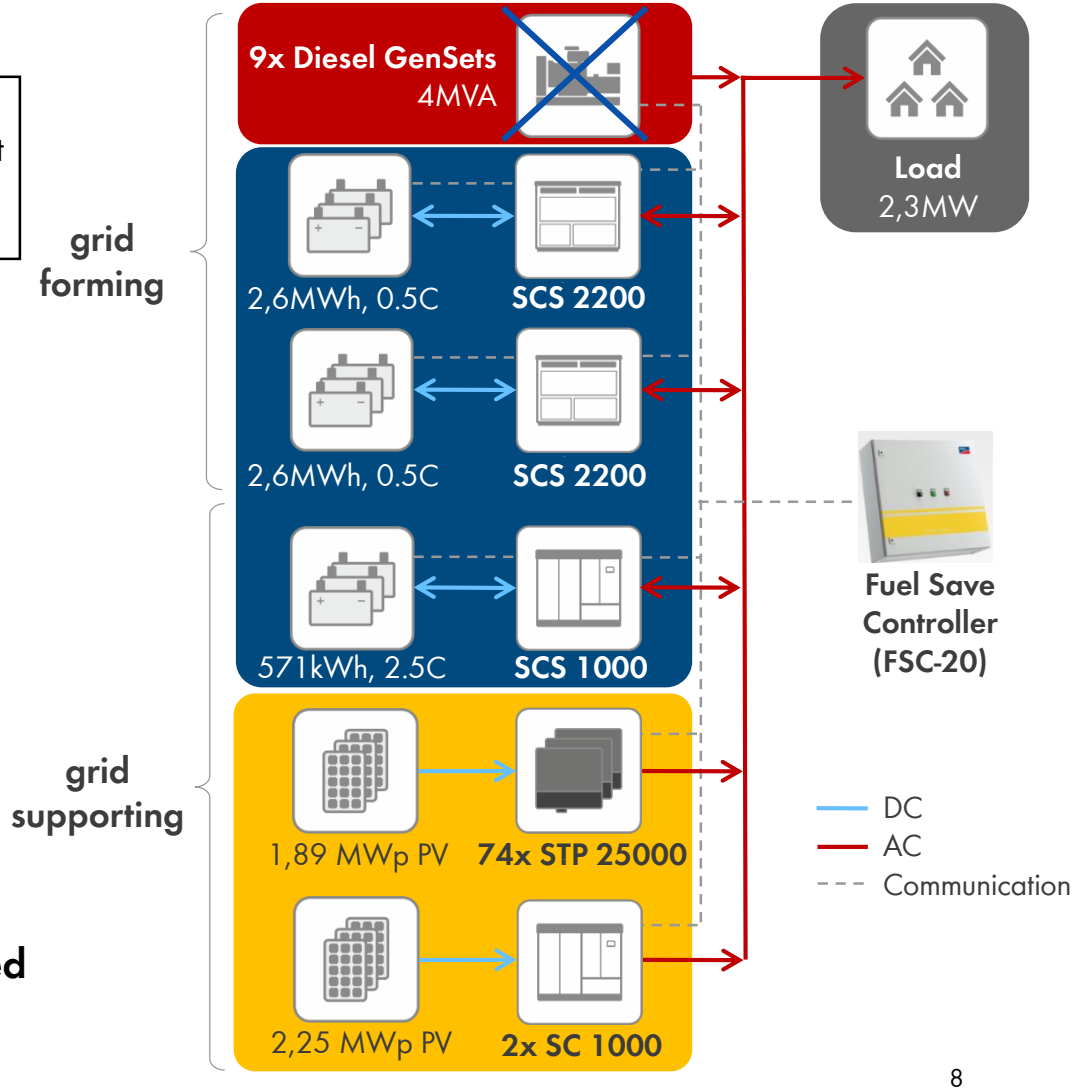
- Peak load: 2,3 MW
- Energy consumption: 14 GWh/a
- PV energy yield: 6,4 GWh/a
- PV energy coverage: >46 %
- PV total power: 4,15 MWp
- Battery capacity: 5,9 MWh
- Diesel power: 4 MVA
- Diesel savings: >1,7 Mio. l/a
- CO2 savings: 4560 t/a

Experience after >1,5 years: superior reliability, stability and power quality at 100% inverter-based grid operation and renewable energy supply for more than 10 hours per day thanks to utility-scale PV & Grid Forming battery storage solution

3. Schömann et al.: „Experiences with large Grid Forming Inverters on the Island St. Eustatius, Portability to Public Power Grids“, 8th Solar Integration Workshop 16-17 October 2018 Stockholm, Sweden

Operation principle of PV+Diesel+Storage system on St. Eustatius





> **Stable parallel operation of inverter- & synchronous machine-based generation with grid supporting & grid forming control**

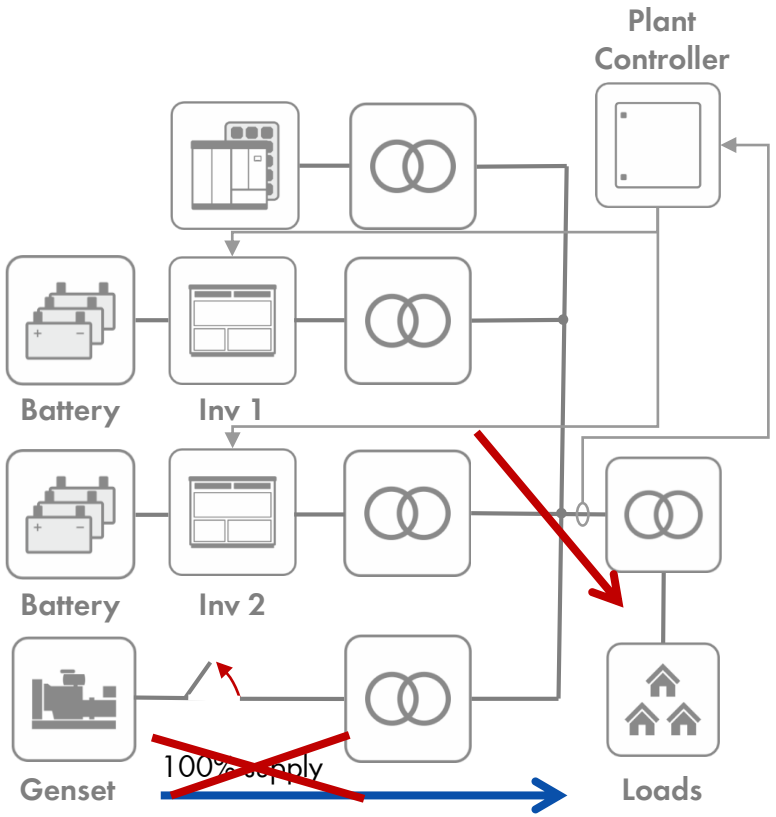
Inertia and immediate load sharing:
Real world generator shut down test in an island system

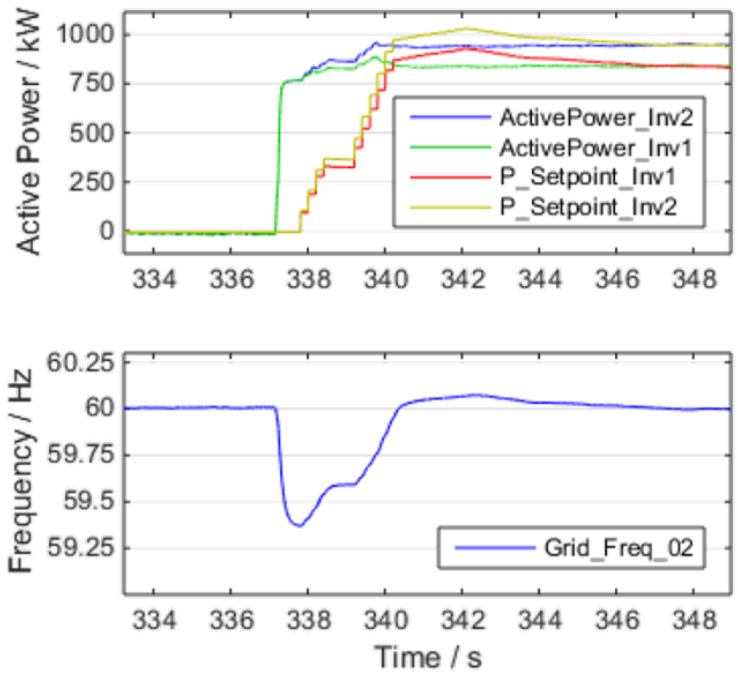
Load is supplied by diesel genset with battery inverters in parallel standby

Diesel genset is shut down

Battery inverters take over the load immediately, sharing load equally

Setpoint for the reference point of f(P)-droop is adjusted (ext. control)





> **Capability proven in Island projects can be applied in grid connected applications**

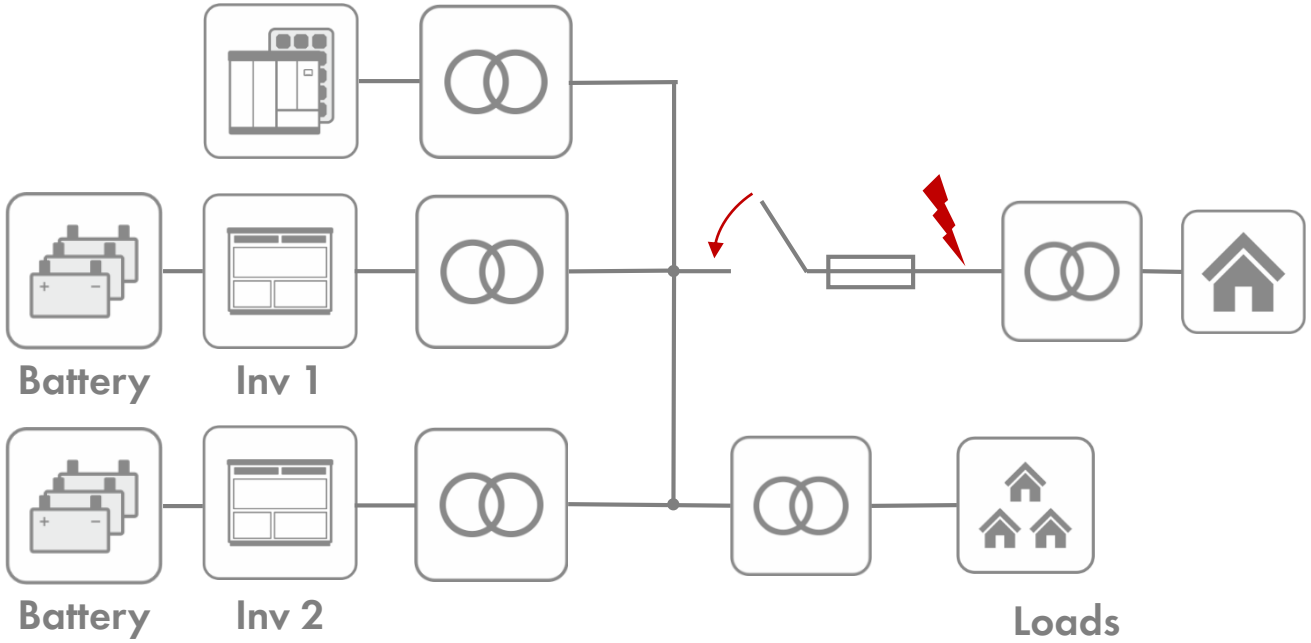
Fault Ride Through Tests on St. Eustatius

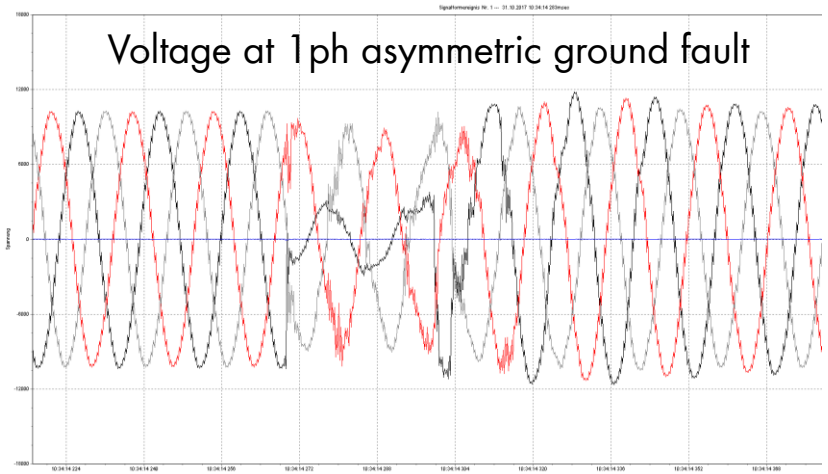
Test Setup: Grid segment is artificially shorted and connected to the Grid in Operation

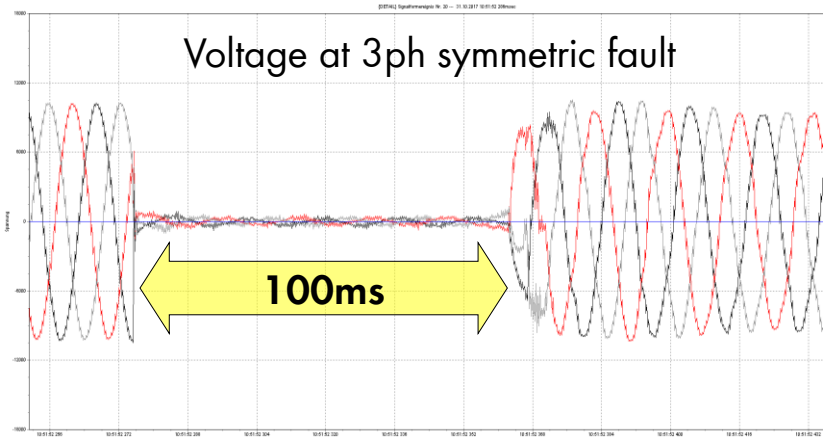
Successful fault ride through tests on the island of St. Eustatius

LVRT acceptance tests in grid operation <u>without Diesel genset</u>[1]:

1) Installation an artificial faults on 12,5 kV medium voltage level
2) Connection of the faulty grid segment







- **Fast fault clearing within 100ms by PV & Grid Forming storage inverters <u>without</u> current contribution of genset**
- **Immediate grid voltage restoration after fault clearing**

1. Schömann et al.: „Experiences with large Grid Forming Inverters on the Island St. Eustatius, Portability to Public Power Grids“, 8th Solar Integration Workshop 16-17 October 2018 Stockholm, Sweden

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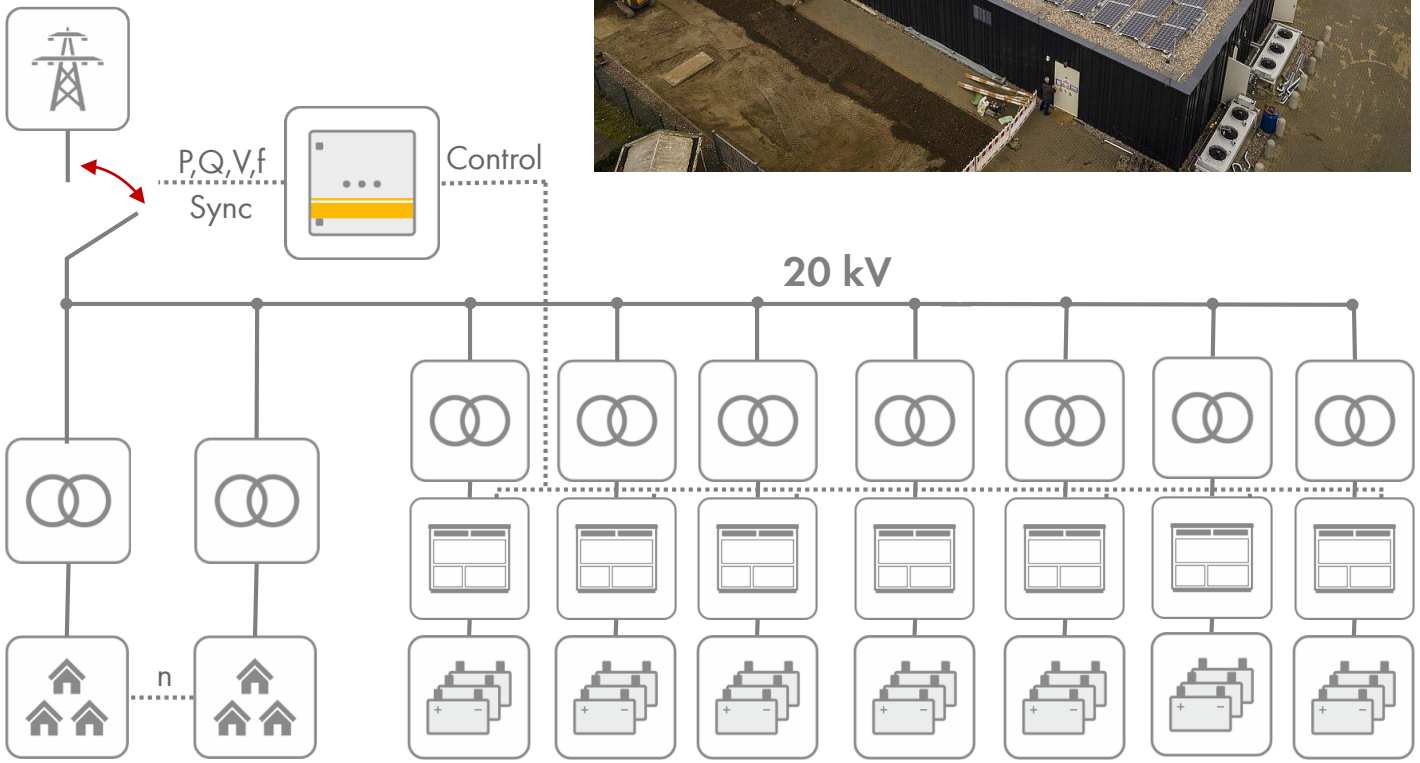
Bordesholm 10MW/15MWh battery storage facility

Successfully tested capabilities in grid-tied and microgrid operation on 30.11.2019

- Uninterrupted supply with power & renewable energy at intentional islanding test
- Substitution of public electricity for >1 hour

Further capabilities

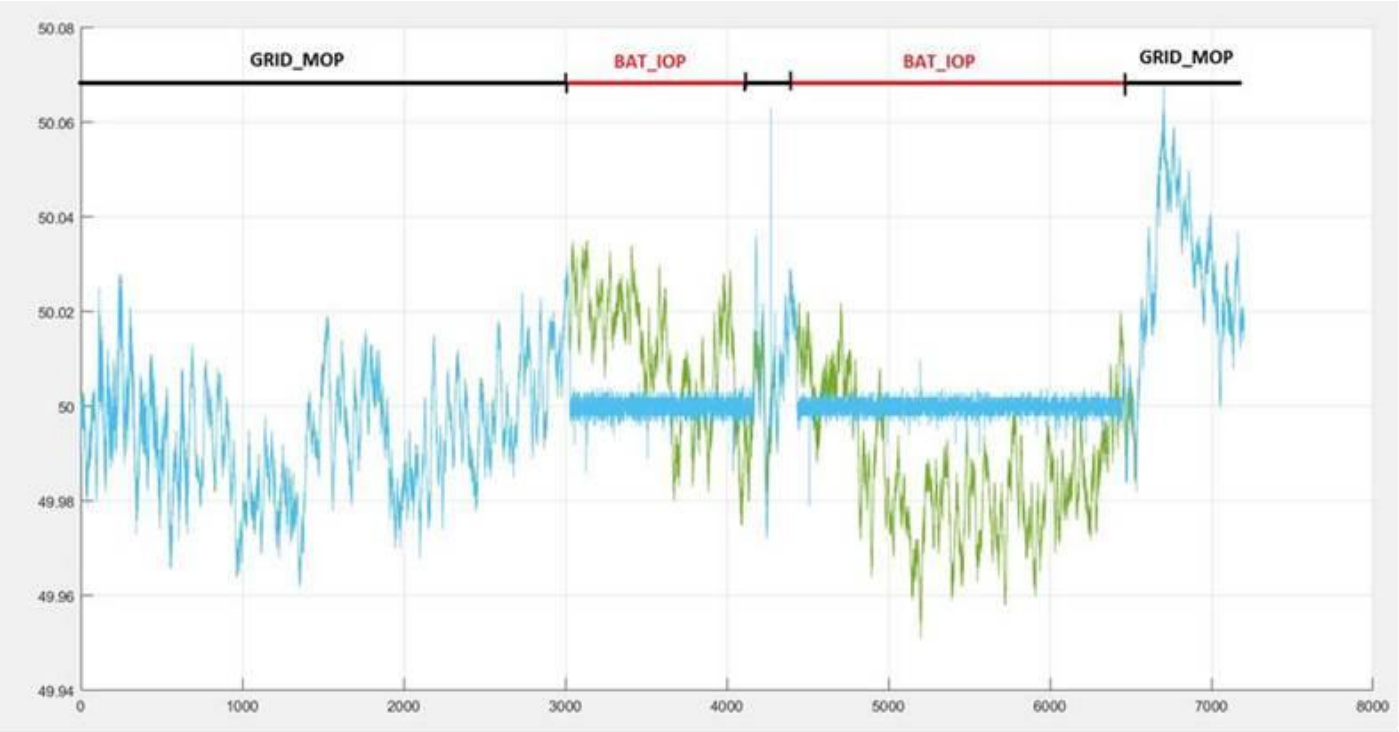
- Frequency regulation by active power reserve
- Voltage support by reactive power
- Feed-in management
- Grid restoration by black start & synchronisation
- Inrush current limitation



Project Integration done by RES Germany GmbH for the local utility company Versorgungsbetriebe Bordesholm GmbH

Intended islanding, energy supply & stabilization of a village with Grid Forming storage power plant in Bordesholm

- Storage plant is able to take over the supply of a 7500 inhabitants' village in case of a grid outage



lolsteiner Zeitung 15

IONALAUSGABE DER KIELER NACHRICHTEN KN 02.12.19

Anspannung, Entspannung: VBB-Geschäftsführer Frank Günther (53, rechts) und Prof. Eberhard Waffenschmidt (55) von der Technischen Hochschule Köln nehmen Bordesholm vom Netz. FOTO: MICHAEL GÖRMANN

Kein Stromausfall beim Stromausfall

Bordesholm eine Stunde abgekoppelt – Batteriespeicher hat seinen Test bestanden

VON MICHAEL GÖRMANN

BORDESHOLM. Es war eine Mischung aus Richtfest und Diavortrag, als am Sonnabend in Bordesholm ein energiepolitischer Meilenstein von europäischer Bedeutung gesetzt wurde. Eine durchgelegte Materialhalle der Versorgungsbetriebe (VBB), ein paar Biergarnituren, ein etwas lichtmüder Beamer, viele Zahlen – kurzum: eine Inszenierung, bei der Worte wie „Glamour" oder „Hollywood" nicht gerade die allererste Assoziation sind. Und als dann der große Moment kam, als Bordesholm um 15 Uhr sich selbst vom europäischen Stromverbund abkoppelte, da war das Ergebnis völlig unspektakulär. Doch genau diese Ereignislosigkeit war das Besondere. Denn Herzklopfen hatten die Verantwortlichen zuvor selbstverständlich trotzdem gehabt.

So kurios es klingt: Dass absolut nichts passierte, war für die Beteiligten wirklich aufregend. Dass die sprichwörtlichen Lichter eben nicht ausgingen, keine Supermarktkasse streikte, nicht irgendwo ein Diesel-Notstromaggregat anspringen musste. Dass vielmehr die Biogasanlage im Nachbarort Brüggie, die 260 meist privaten Solaranlagen in Bordesholm, Blockheizkraftwerke und ein phänomenaler Batteriespeicher den Kreislauf der gesamten Stadt problemlos übernehmen und ihr Herz im Takt halten können. Und dass man den Zeitpunkt des Umschaltens nicht einmal bemerken würde, das hatte niemand so erwartet.

„Es müssen etwa 50 Millisekunden gewesen sein, dann sprang unser System schon an", sagte VBB-Geschäftsführer Frank Günther (53) hoch erfreut. Und Prof. Eberhard Waffenschmidt (55) von der Technischen Hochschule Köln, die das Experiment begleitet, korrigierte lachend: „Nichts da, es ging sogar noch viel schneller!" Der Batteriespeicher, seit Frühjahr 2019 in Betrieb, hat damit seine Bewährungsprobe bestanden. Knapp 48 000 kleine, flache

> „Es ist schon peinlich, dass vom Land niemand gekommen ist. Wo ist Daniel Günther?
>
> Jörg Niedersberg, VBB-Aufsichtsratschef

Samsung-Akkus, wie sie auch in Handys verbaut werden, bilden den Puffer zwischen den energieliefernden Kraftwerken und den Energieabnehmern.

Die Akkus werden ständig zwischen 17 und 20 Grad klimatisiert und mit rund 50 Prozent Ladezustand bei Laune gehalten. Dann fühlen sie sich am wohlsten und sollen schätzungsweise 20 Jahre leben. Sie haben genug Power, um gleichzeitig 500 Teslas oder fünf Millionen iPhones zu laden. Da die Versorgungsbetriebe jährlich rund eine Million Euro mit Stromeinspeisung verdienen wollen, könnte das zehn Millionen teure System also ab 2029 Gewinn abwerfen.

Doch es geht nicht nur ums Geldverdienen, wie der ehrenamtliche VBB-Aufsichtsratsvorsitzende, Rechtsanwalt Dr. Jörg Niedersberg (60), betont. Der Batteriespeicher sei ein Leuchtturmprojekt von internationaler Strahlkraft.

Damit werde zum ersten Mal bewiesen, dass ein komplettes, öffentliches Stromversorgungsnetz, gespeist aus 100 Prozent erneuerbarer Energie, frequenzstabil als Inselnetz gefahren werden kann. Mit anderen Worten: Wenn im europäischen Verbundnetz einmal eine Störung auftreten sollte, gehen zumindest in Bordesholm die Lichter noch lange nicht aus. Rund 2,5 Megawatt betrug zum Zeitpunkt des Tests die Leistungsabnahme im Ort, doch weil die Sonne schon fast keine Kraft mehr hatte, wurden nur rund 1,5 Megawatt von der Biogasanlage und den Solaranlagen eingespeist.

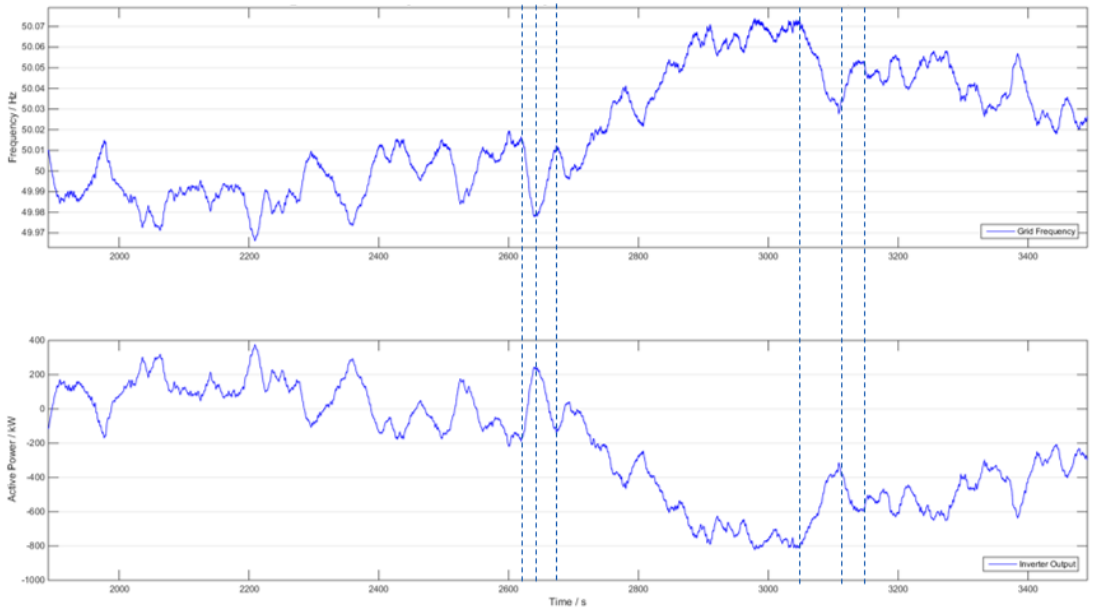
Die Differenz kam aus dem Batteriespeicher. Der zeigte sich von der Belastung völlig unbeeindruckt und lieferte mit konstant 50 Hertz ab – stabiler sogar als das Verbundnetz, wie Frank Günther auf der Leinwand eindrucksvoll belegen konnte.

In die allgemeine Freude über den erfolgreichen Test mischte sich bei Aufsichtsratschef Niedersberg auch bittere Enttäuschung: „Es ist schon peinlich, dass vom Land Schleswig-Holstein niemand gekommen ist. Wo ist Daniel Günther? Es wird immer groß geredet, aber wenn mal jemand einen Schritt wagt, ist keiner da."

For further information on the plant, see (German): https://www.ardmediathek.de/ard/player/Y3JpZDovL25kci5kZS84NTI2ODU2NC02YTliLTRlZDYtOWUxYi01MmYwNDNmMzJkZGE/ and http://www.waffenschmidt-aachen.de/projekte/2017-10_Bordesholm_Batterie/Bordesholm-Batterie.htm

For utilizing the full potential of Gridforming inverters in public electricity grids, grid codes need to be adapted

Grid-parallel operation of Gridforming inverters



Present grid codes often neglect opportunities given by inverter-based Gridforming :

- Grid codes were designed with focus for grid supporting operation
- Modification is highly desired

Unclear requirements considering (among other topics):

- Evidence of grid forming behaviour
- Fault-ride-through behaviour
- Behaviour at operational limits of the inverters
- Prevention and behavior at unintended islanding
- Characterization of inverter-based inertia
- Common test procedure and quality criteria
- Interaction with grid protection mechanisms

› **Conformity with grid codes needs to be clarified for the particular application**

Thank you for your attention!

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