SMA AMERICA

TECHNOLOGY WORKSHOP

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INVERTER-BASED GENERATION TECHNOLOGIES

There are 3 basic technologies driving inverter-based projects today.

Key attributes:

PV Only

- DC Voltage varies as Inverter tracks MPP of PV array.
- Fast AC Voltage control possible.
- Frequency control possible in **one direction** only (droop).
- Slow frequency response.
- Grid-forming not used.

PV + DC-Coupled Stg

- DC voltage of battery interfaced to inverter via a DC-DC converter.
- Fast AC Voltage control possible.
- Frequency control possible with sufficient battery charge.
- Charge battery from the PV array and/or the grid.
- Voltage & Freq. response time same as PV.
- Grid forming possible; currently not implemented

AC-Coupled Stg

- DC voltage is somewhat fixed as governed by the battery.
- Limited AC Voltage control possible. Q related to DCV.
- Frequency control possible with sufficient battery charge.
- Charge the battery from the grid only.
- Fast frequency response possible (<250 ms).
- Grid-forming and black-start implemented today.

PV Only
PV + DC-Coupled Stg
AC-Coupled Stg

PLANT CONTROL LOOP AND COMPONENTS – CONTROL MODES

Active Power

> Feed in Protection
> Power Frequency Response
> Active Power Reserve
> Cloud Ramp and Measurement Dispatch
> External setpoints and limitations
> Ramp rate control

Reactive Power

- Q(V) / Voltage Droop
- Fixed CosPhi
- Voltage Control
- CosPhi(P)
- Q at night
- External setpoints and limitations
- Ramp rate control

Apparent Power

- Limitation with prioritization of active or reactive power
- External setpoints and limitations

PV Only
PV + DC-Coupled Stg
AC-Coupled Stg

BATTERY INVERTER OPERATION MODES

Current Control Mode (Grid Following)

The so-called grid tied inverters operates as a current source to achieve the requested active power and reactive power set points.

The inverter needs a grid voltage established by other generators to synchronize to and feed-in or draw power of the grid.

In this mode the inverter has full control over its current wave form (amplitude and angle). The inverter can achieve the requested set-points faster as it controls the current directly.

In case of a failure, the inverter can set its current to the requested values as per the grid codes.

Voltage Control Mode (Grid Forming)

The so-called grid forming inverter operates as a voltage source to control the voltage and frequency.

The inverter can work in parallel to other generators or stand-alone.

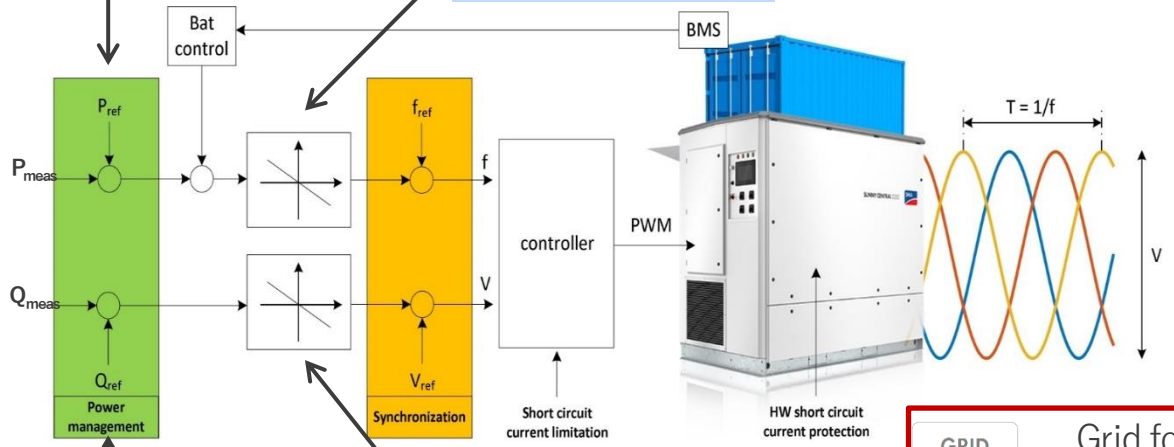
In this mode it can also control the active power and reactive power to the given set-points, not by controlling the current; but, by directly adjusting the output voltage (similar to synchronous generators).

In case of a failure, the inverter can only limit the current magnitude but not the angle.

BASICS OF GRID-FORMING CONTROL

P Setpoint:
(Active power at nominal frequency)

Active power/ frequency -droop



Reactive power/ voltage- droop

Q Setpoint:
(Reactive Power at nominal voltage)

GRID FORMING TECHNOLOGY

Grid forming is an inverter operation that enables the inverter to form the grid voltage and frequency in AC power grids

There are many areas of application for Grid Forming solutions enabling new beneficial values and improved system strength

Grid connected systems or Microgrids

An appropriate inverter system design is required for grid forming operation, depending on the application

STARTING SEQUENCE IN GRID FORMING MODE

There are two ways to start in grid forming mode. This depends on the application

Grid Side Starting

In this starting procedure, the inverter starts from the grid side. The grid can be either public grid or genset grid.

- The inverter charges its DC-Link capacitors from the grid.
- Adjusts its DC voltage to the battery voltage,
- Then, connects to the battery
- Operates in grid forming mode parallel to the grid or genset
- The grid can then be disconnected, and the system operates in stand alone with the inverter controlling the voltage and frequency

Advantage: No HW for DC pre-charge nor backup system needed

Battery Side Starting

In this starting procedure, the inverter starts from the battery side. An AUX supply shall be provided externally thru back-up system (UPS).

- The inverter charges its DC-Link capacitors from the battery using a DC pre-charge circuit.
- The AC voltage is then ramped up energizing the connected transformer.
- The inverter is now operating in grid forming mode in stand-alone operation.
- Loads can then be switched on to the established grid

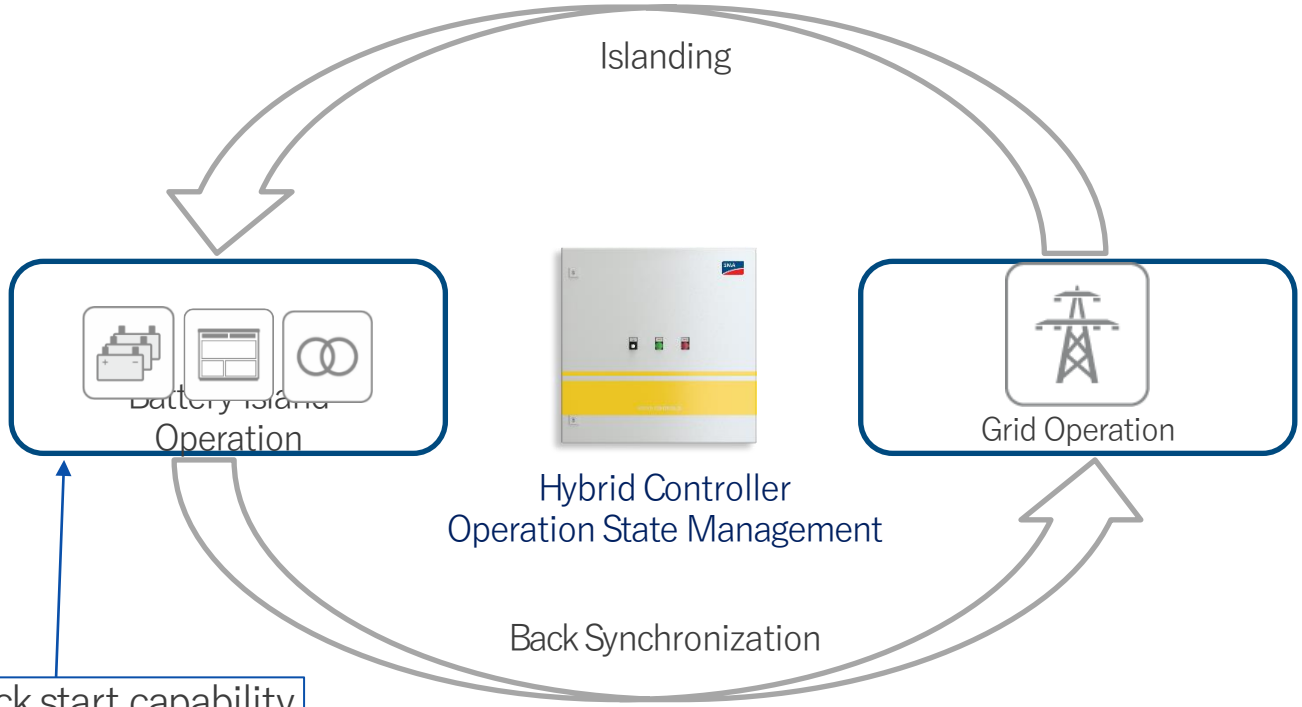
Advantage: start from the battery side is possible

- In both cases, the control signals to the inverter itself and its operation mode **are the same**.
- The difference is in the grid management/configuration function done by the plant controller

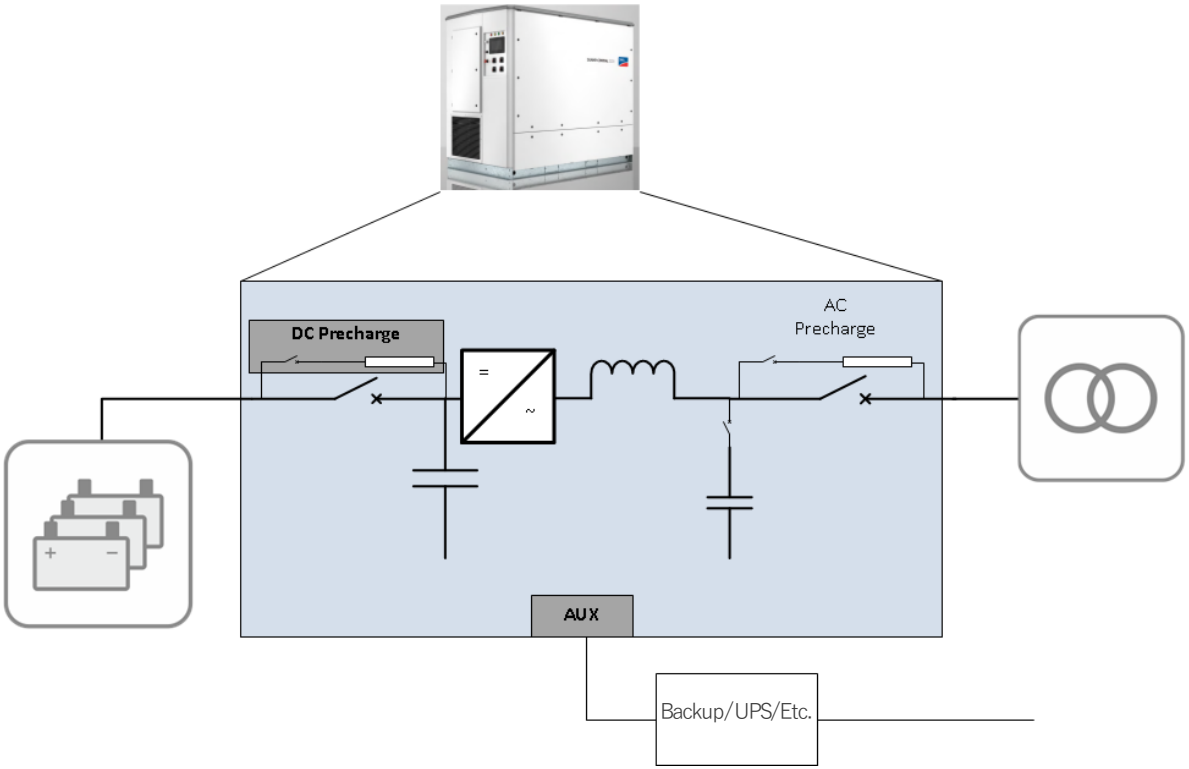
GRID-FORMING WHILE GRID-CONNECTED

NEW

Good for low SCR locations



SCS FEATURES NEEDED FOR BLACK START

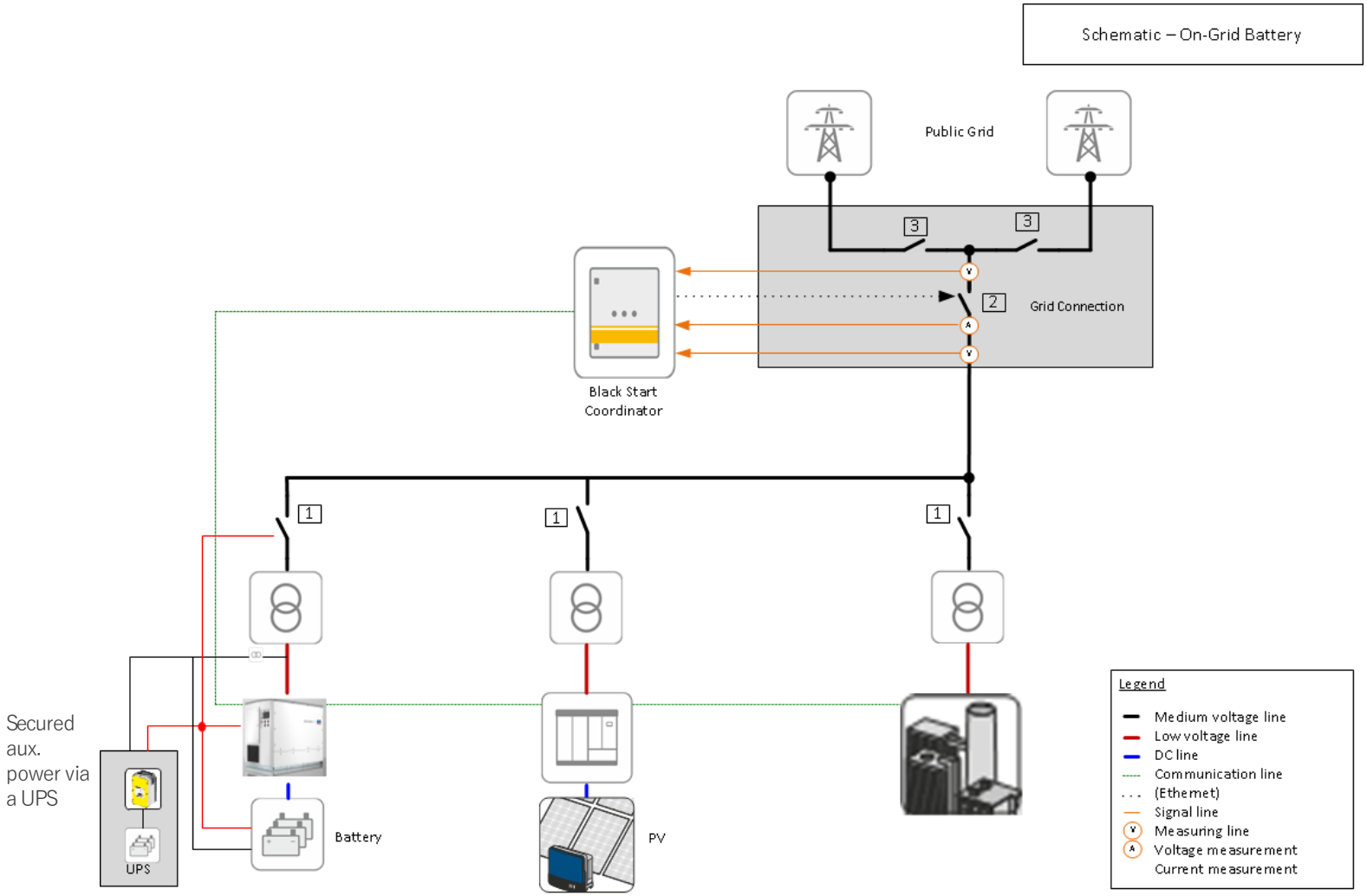


1- Input for external AUX power is required for inverter electronics, switches and fans in the absence of grid.

2- The dc-link capacitors require a precharge from the battery. The battery shall be connected to the inverter to enable this operation.

ILLUSTRATIVE SCHEMATIC OF THE BLACK START FUNCTION

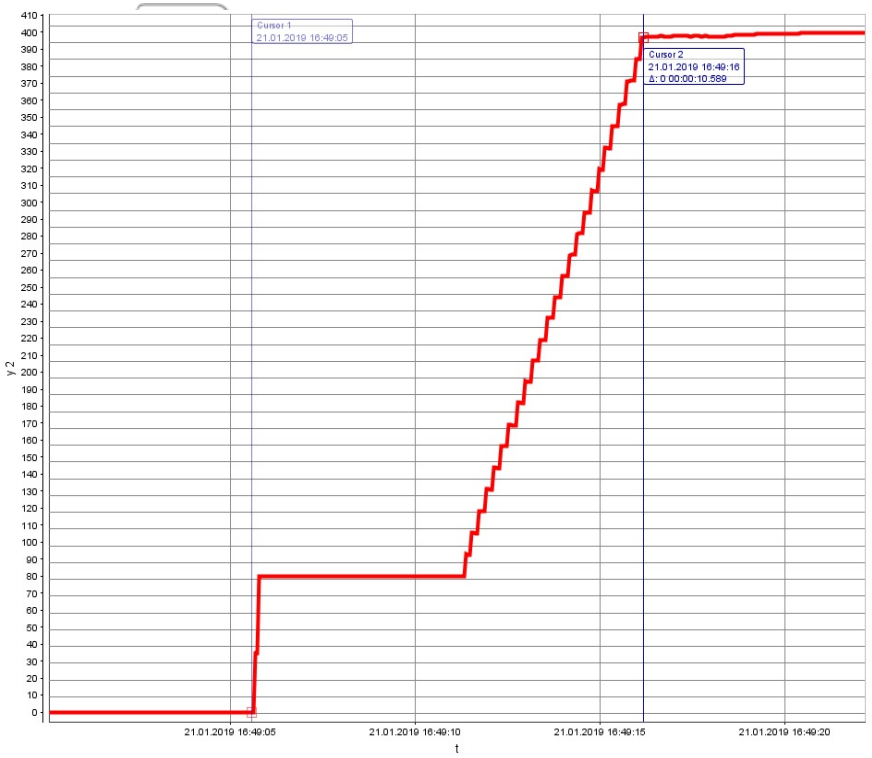
- **Black start is a system level function and requires more than an inverter…**



AC-Coupled Stg

BLACKSTART - CONCEPT

1. HyC detects initial condition
2. Black start command
3. first SCS starts with 20% Unom
4. other SCS synchronize themselves
5. Voltage is ramped up by HyC from 20% to 100% Unom
6. Release signal for load connection
7. Transition to normal operation
8. Total time approx. 30sec



Name	y-Achse	Cursor 1	Cursor 2	Delta	Aktueller y-Wert
MFSC20/ScopeData.UacGrid2	y 2	0	396.772	396.772	400.52

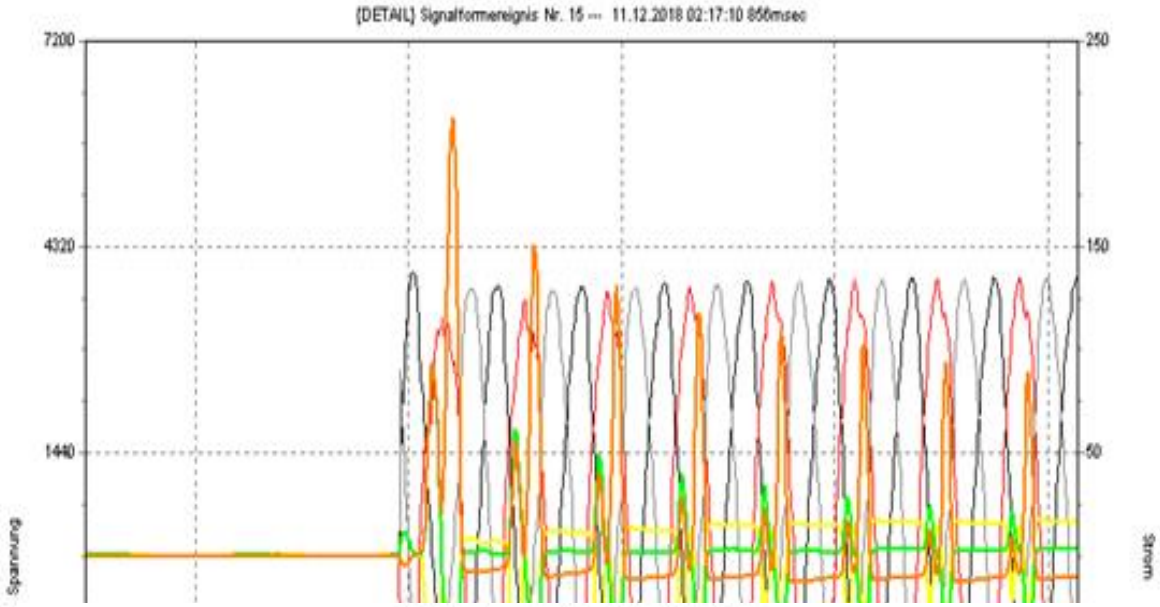
BLACKSTART - TESTS

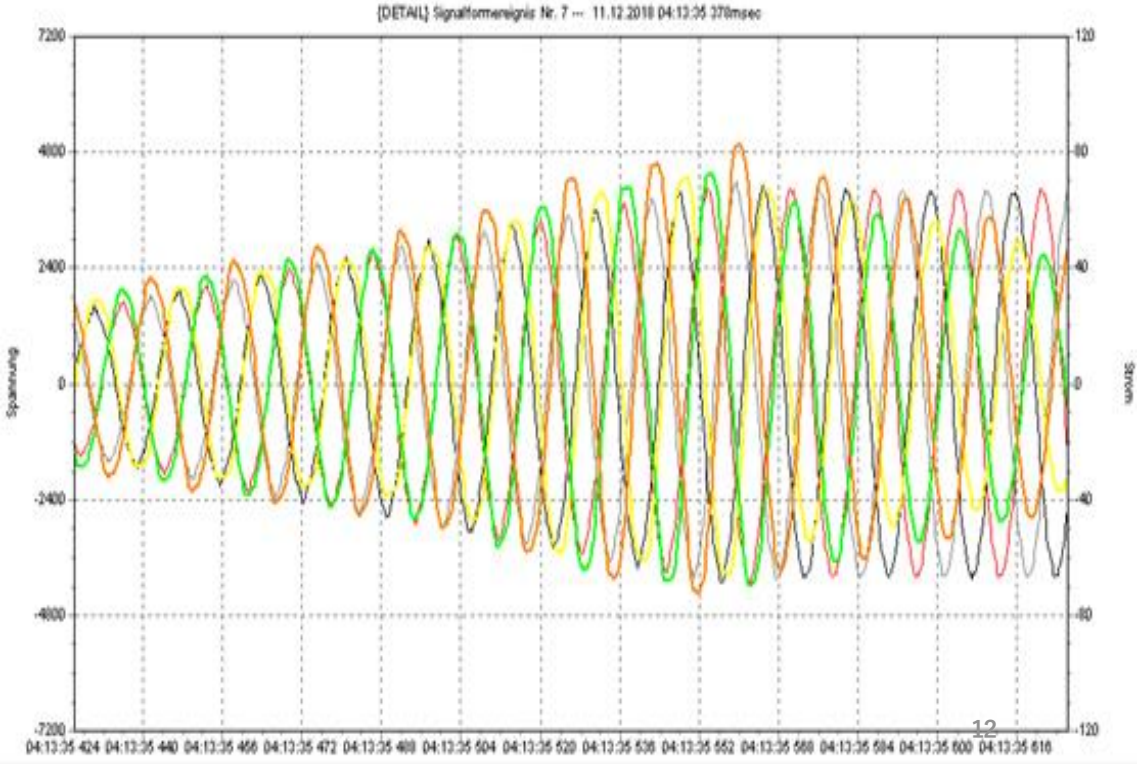
Black start with Gensets

Normal black start with Gensets

Sudden Connection, No Precharge

Transformers are switched on hard without pre-magnetization





Black start with HyC+SCS

- All transformers are connected
- 200ms Ramp-Up of Voltage
- Obviously some loads are also connected
- Significantly lower stress on the components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