Black start from DER

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Black Start Stages

The black start stages:

- Preparation stage
- Network reconfiguring / establishing cranking paths
- Gradual load restoration

A typical restoration plan:

- System status identification: blackout boundaries and location in respect to critical loads, status of circuit breakers, capacity of available black start units, etc.
- Starting at least one black start unit to supply critical loads such as nuclear or large thermal power plants
- Progressive restoration: step-by-step supply of other loads avoiding over and under voltage conditions

The restoration strategies:

- Serial – simpler strategy, slower but more stable
- Parallel – quicker but more complex

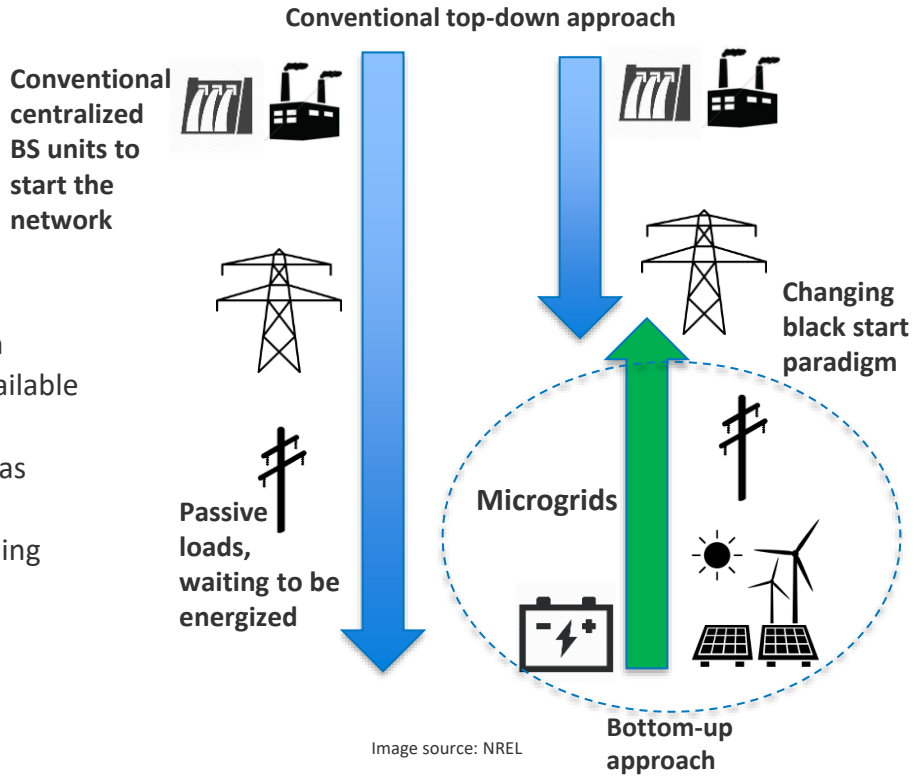


Image source: NREL

Bottom-up Black Start Challenges

Restoration methods:

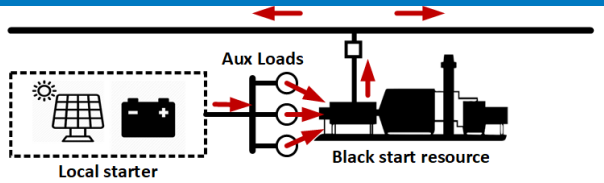
- Single island
- Multiple islands
- Anchor island
- Energizing backbone transmission system
- Combinations of top-down and bottom-up restoration

Main stability challenges:

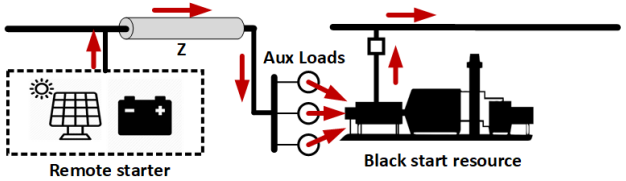
- System strength / low SCR
- Inrush currents
- Protection
- Fault ride-through
- Low/zero inertia
- Voltage stability
- Control Interactions, subsynchronous oscillations, resonances
- Impact of variable generation on load balancing at any stage of black start

Configurations of Integrated PV/BESS Plants for Black Start

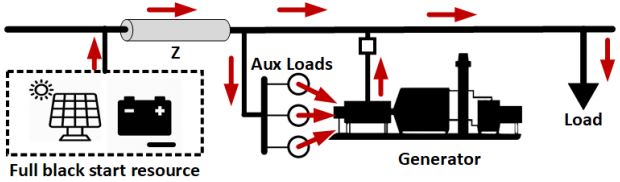
Co-located starter for a black start resource



Remote starter for a black start resource



PV + storage as fully functional black start resource



Collective black start resource

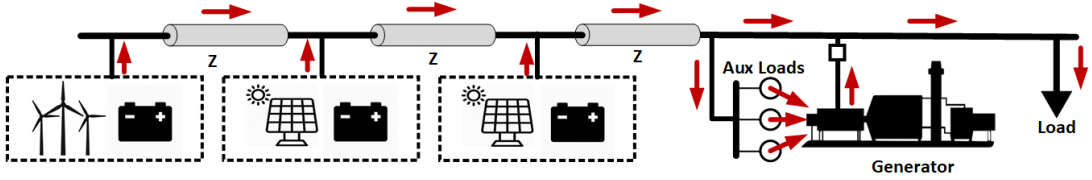
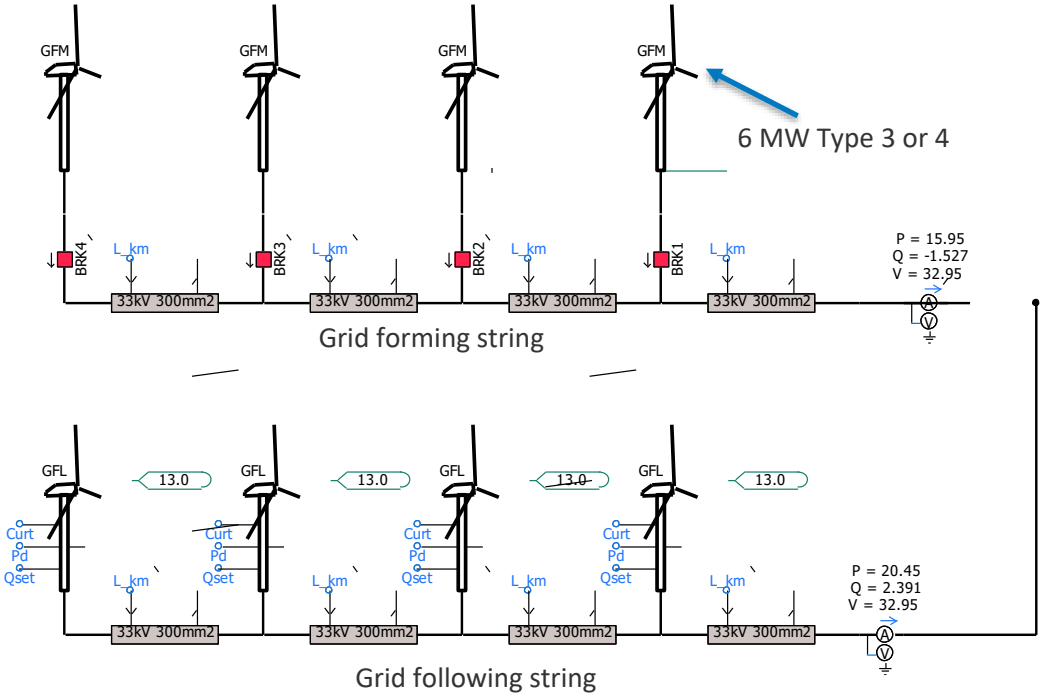


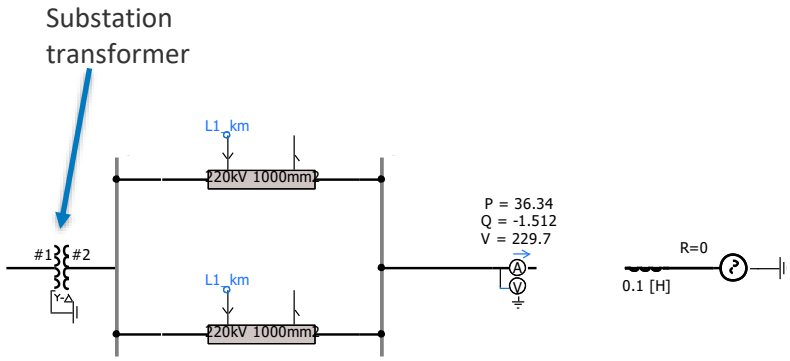
Image source: NREL

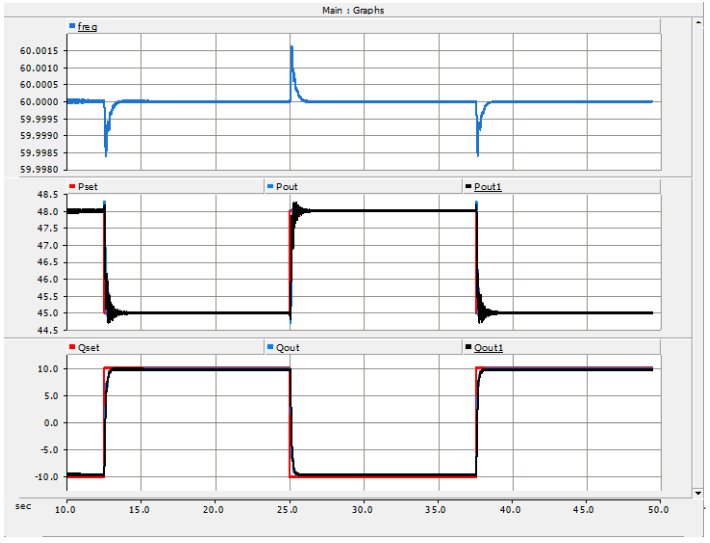
GFM IBRs for Black Start

- WETO: NREL/GE project to demonstrate GFM Type 3 wind turbine operation for black start and islanded operation
- SETO: GE/NREL project to demonstrate GFM PV inverters operation
- WPTO: INL/NREL/ANL project to demonstrate black-start using ROR Hydro power plant coupled with energy storage
- OE: SuperFACTS NREL project to demonstrate operation of GFM BESS with synch condensers for enhanced black-start capability
- GMLC: FlexPower project (NREL, INL, SNL) to demonstrate black-start capability by hybrid wind-PV-storage plants
- Multiple island projects (Puerto Rico, USVI, Aruba, etc.) to develop black-start strategies using GFM resources

Grid Forming Wind Power Plants







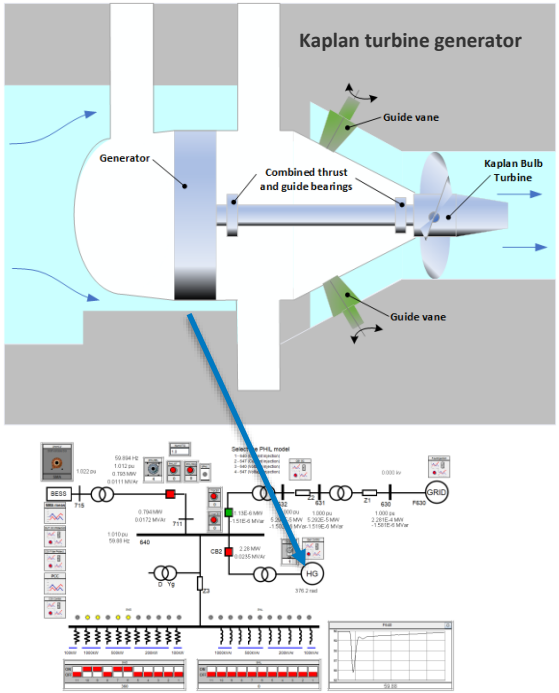
- NREL/GE demonstration using 2.x MW GFM WTG in 2021

Black-start using ROR Hydro Power Plant

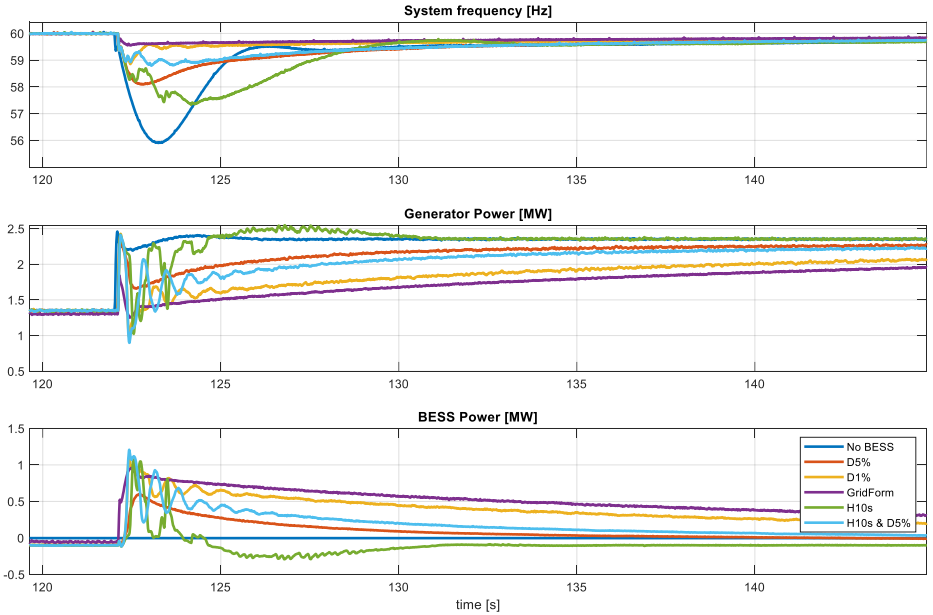
DOE WPTO funded INL/NREL/ANL project

- April 2021 - field demonstration with Idaho Falls Power using 8 MW ROR HPP on Snake River in April/May2021
- INL ultracapacitor energy storage

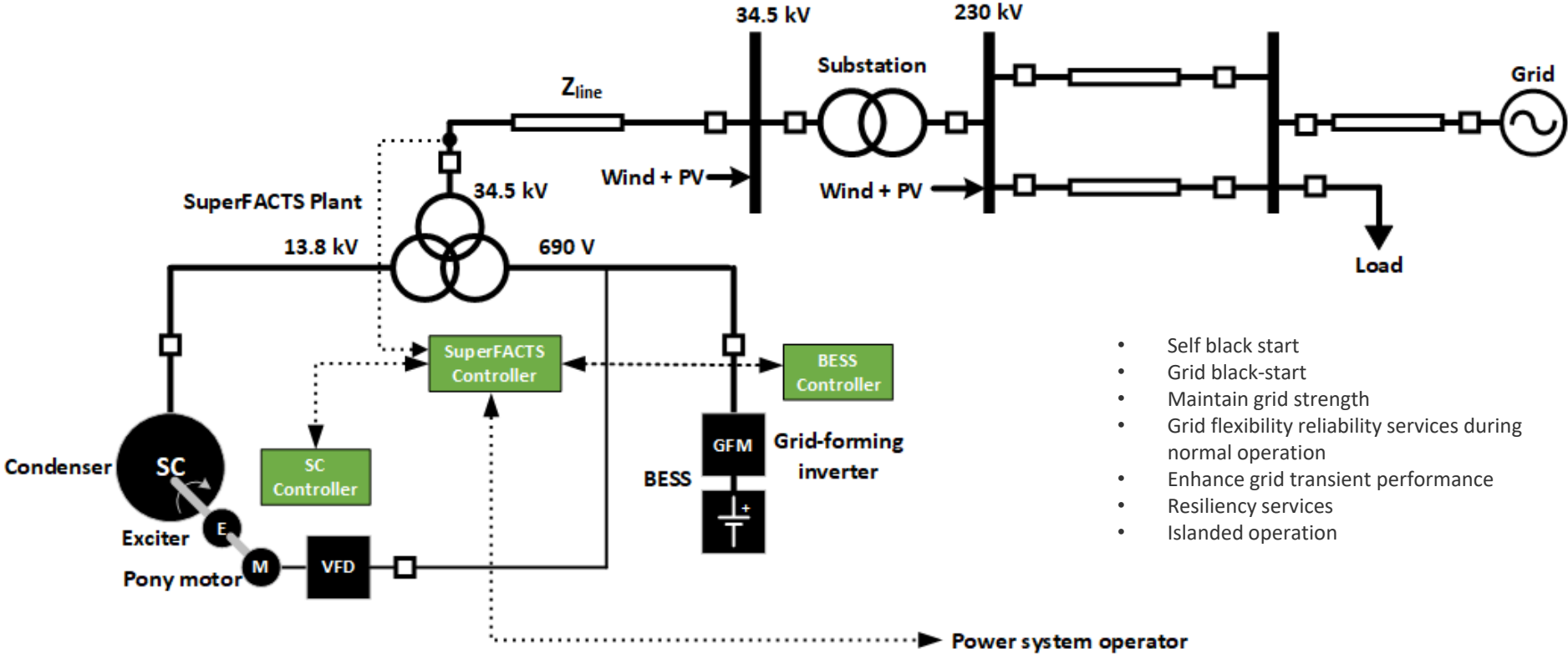
PHIL Implementation of ROR Kaplan turbine generator operating with real BESS



PHIL emulation of different strategies for ROR HPP black start

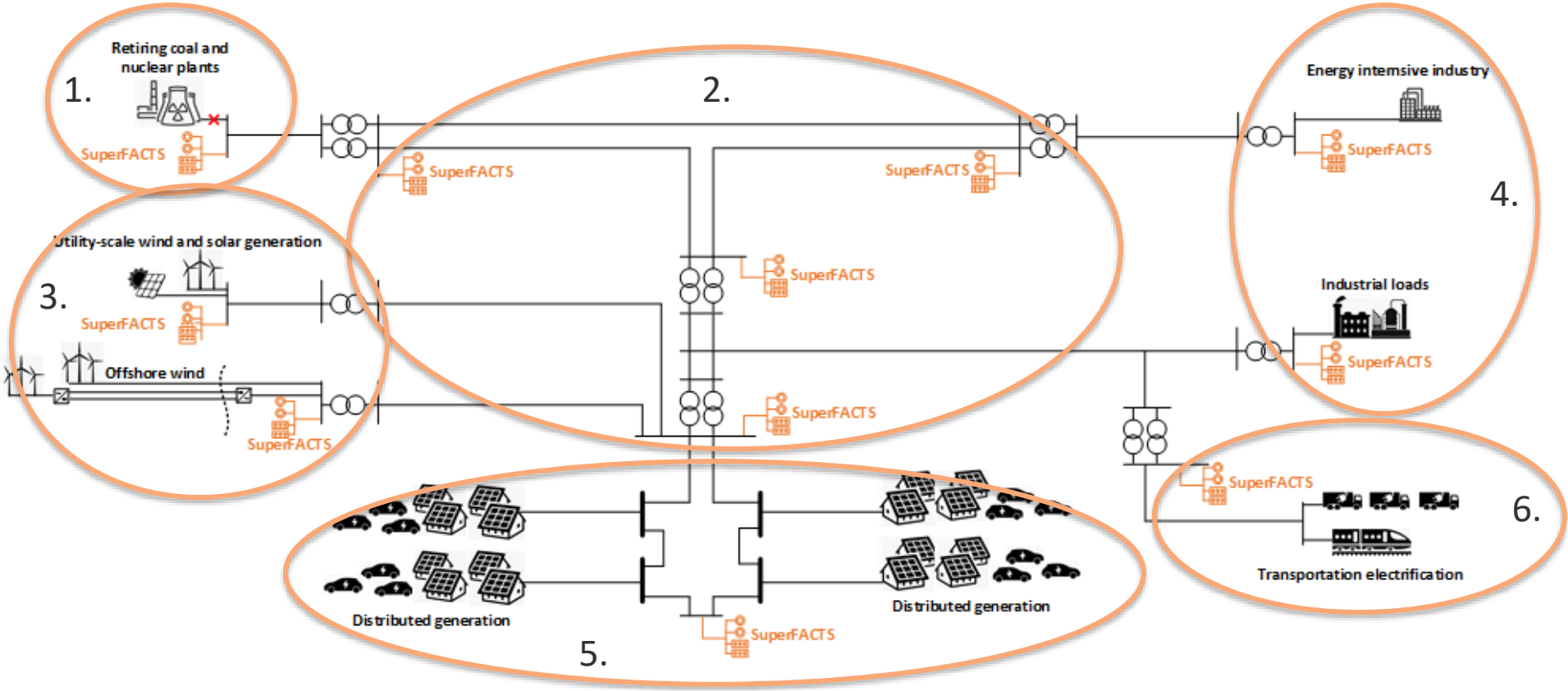


SuperFACTS Conceptual Diagram

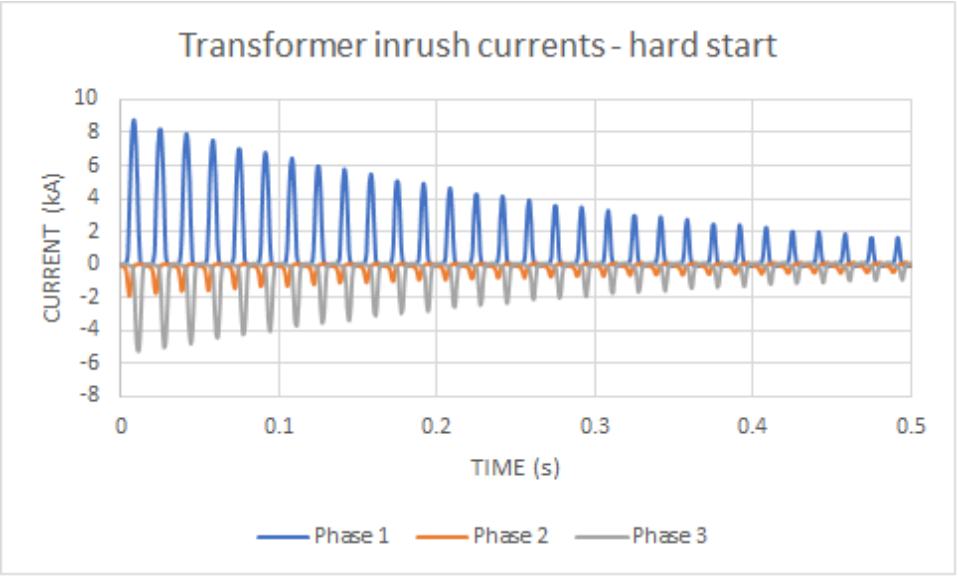


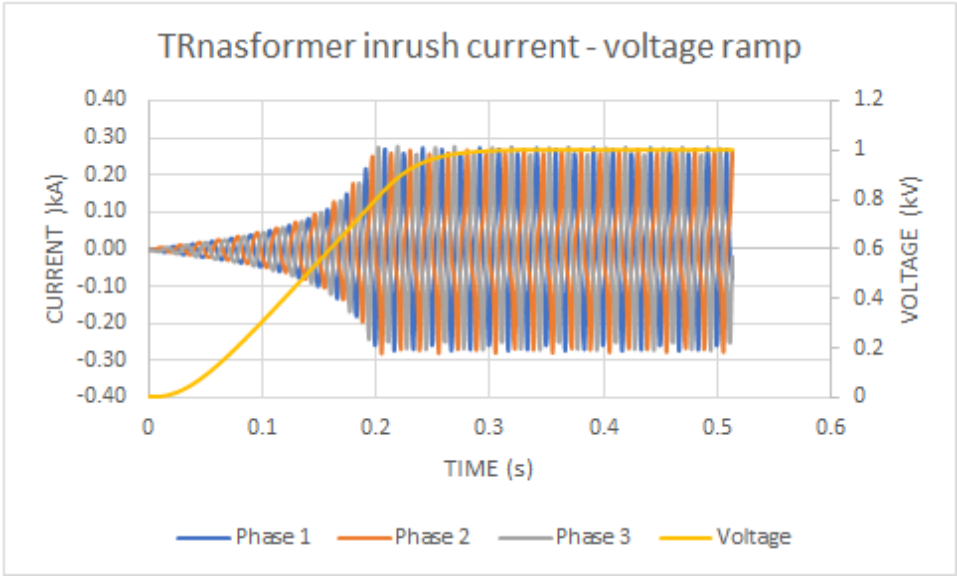
- Self black start
- Grid black-start
- Maintain grid strength
- Grid flexibility reliability services during normal operation
- Enhance grid transient performance
- Resiliency services
- Islanded operation

SuperFACTS Use Cases



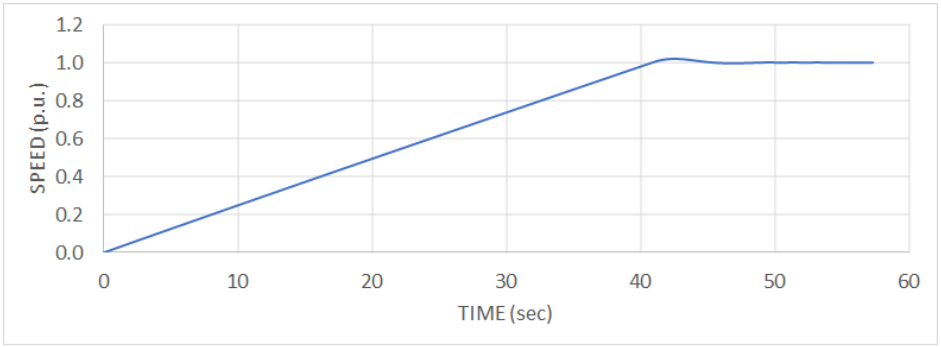
Transformer Energizing with GFM BESS – Soft Start

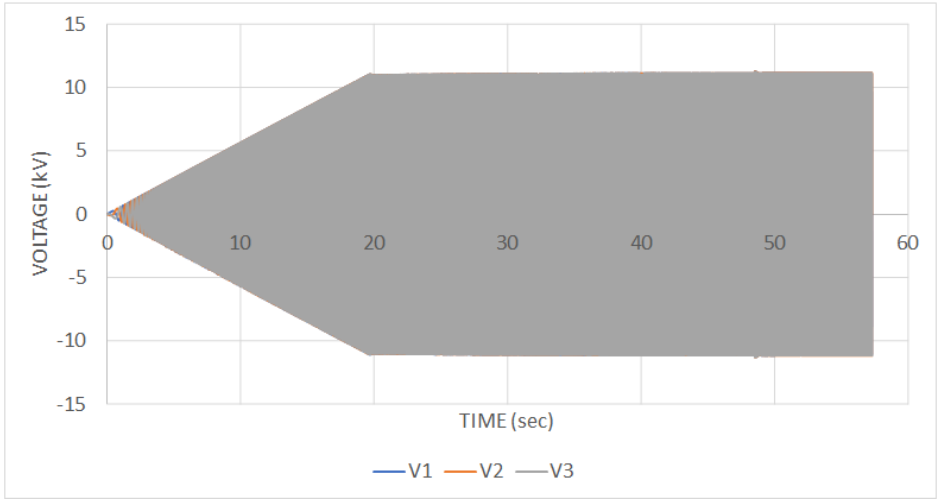




- Voltage ramping by GFM BESS allows limiting inrush currents in transformers to insignificant levels

Synchronous Condenser Acceleration with Pony Motor

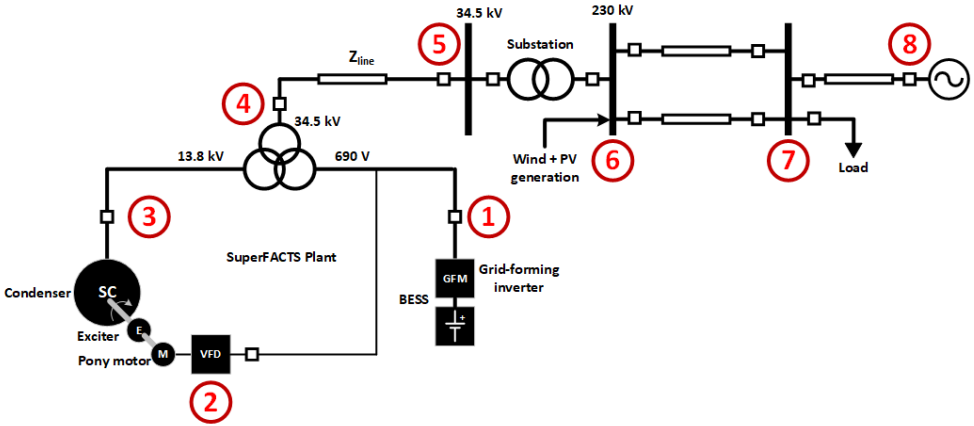


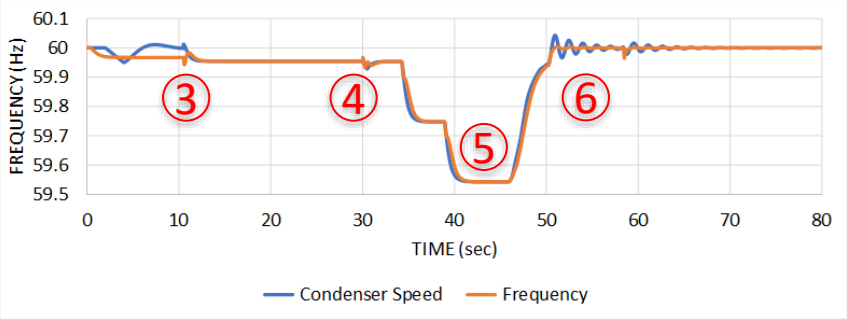


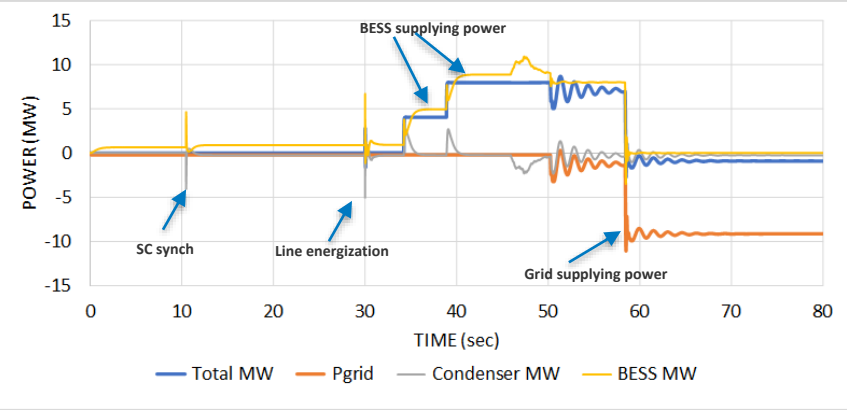
- VFD motor can be used to spin the SC during black start event bringing it to synchronous speed for synchronization with GFM BESS

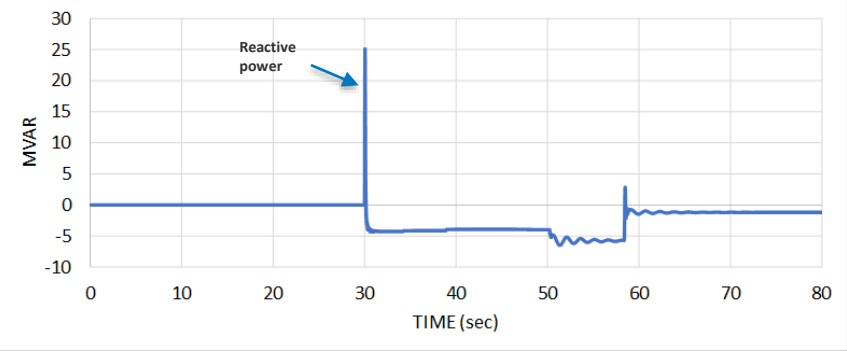
Black start use case

- Self black start first
- Energizing loads
- Connection to the grid

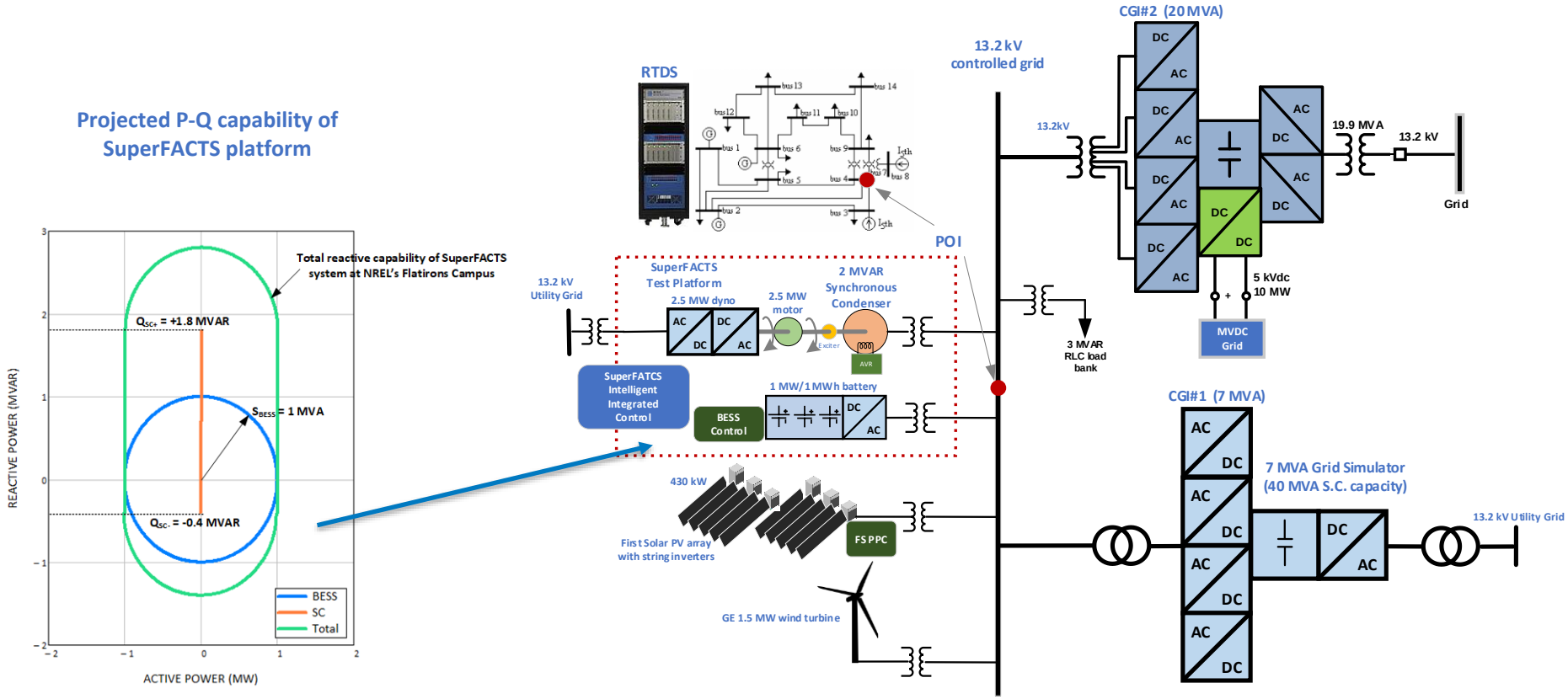








SuperFACTS Test Platform



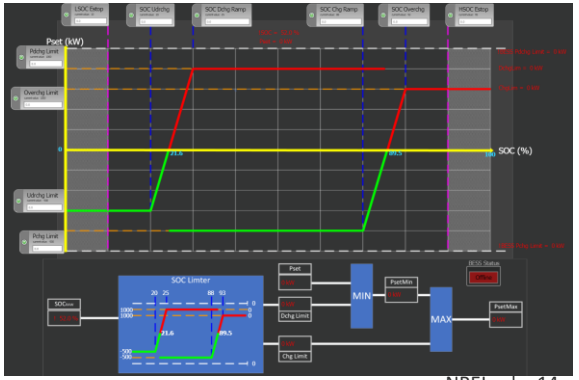
Source: NREL

Microgrid Operation at **NREL Flatirons Campus**

Image by Josh Bauer, NREL

Image from Flatirons Campus meteorology research tower camera

- GFM BESS controls; f-P and V-Q droop, additions P-SOC droop
- Black start controls GFM BESS (SMA inverter)
- Using frequency to control variable generation and BESS SOC



- Substation device failure forced black-start and stand-alone microgrid operation at **NREL Flatirons Campus**

Flatirons Campus 24-hour 100% Renewable Microgrid
October, 2020

Snapshot of Flatirons Campus Microgrid Operation, October 2020

Summary

- Today and future restoration strategies should align with the changing network paradigm
- Modern grid forming inverters can contribute into black start / restoration with more superior reactive power capabilities compared to conventional synchronous generators
- Inherent IBR current limit is one most important factor for black start applications and islanded operation
- More field demonstrations needed to build confidence
- Business models for IBRs to provide black start
- Standardization of grid forming / black start controls for IBRs

Comparison of reactive capabilities by different resources

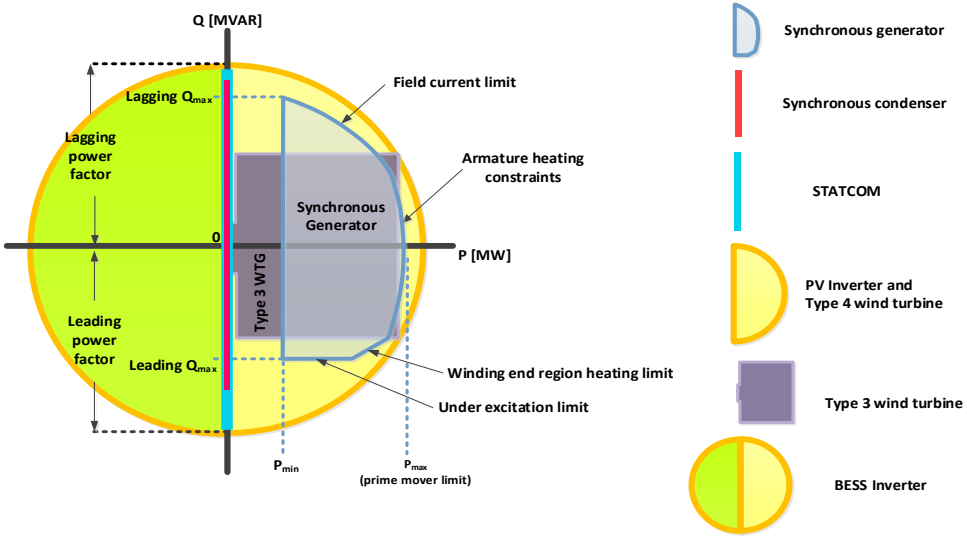


Image source: NREL

Thank you

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