



Black start from DER

V. Gevorgian, S. Shah, P. Koralewicz, R. Wallen, E. Mendiola
NREL

ESIG 2021 Spring Technical Workshop
3/30/2021

Black Start Stages

The black start stages:

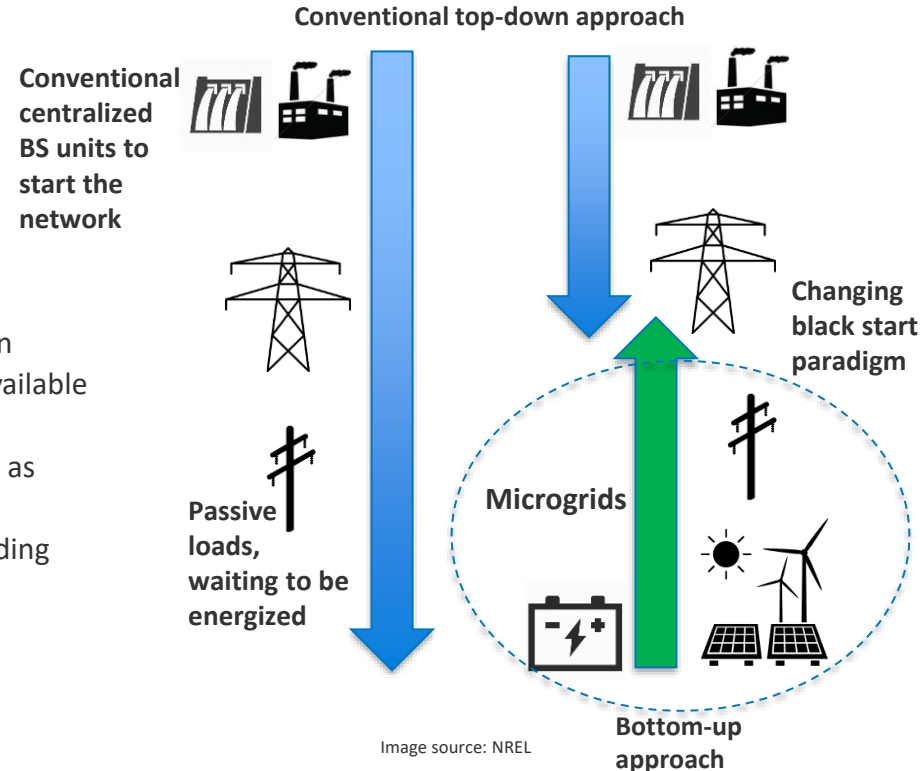
- Preparation stage
- Network reconfiguring / establishing cranking paths
- Gradual load restoration

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



Bottom-up Black Start Challenges

Restoration methods:

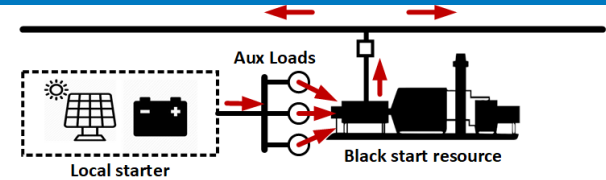
- Single island
- Multiple islands
- Anchor island
- Energizing backbone transmission system
- Combinations of top-down and bottom-up restoration

Main stability challenges:

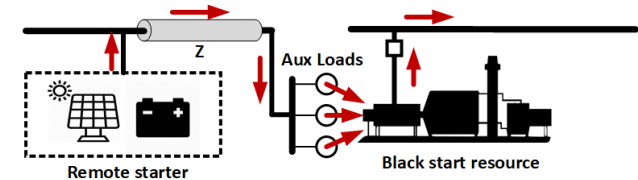
- System strength / low SCR
- Inrush currents
- Protection
- Fault ride-through
- Low/zero inertia
- Voltage stability
- Control Interactions, subsynchronous oscillations, resonances
- Impact of variable generation on load balancing at any stage of black start

Configurations of Integrated PV/BESS Plants for Black Start

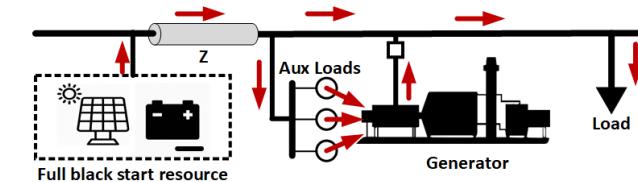
Co-located starter for a black start resource



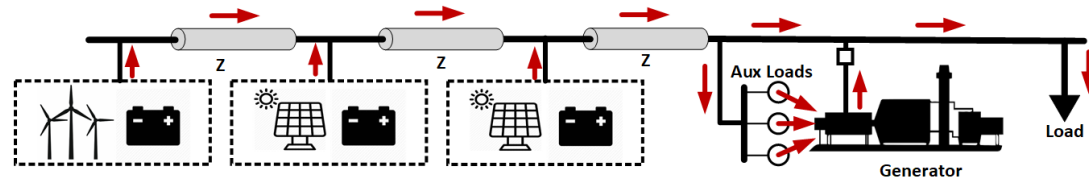
Remote starter for a black start resource



PV + storage as fully functional black start resource



Collective black start resource



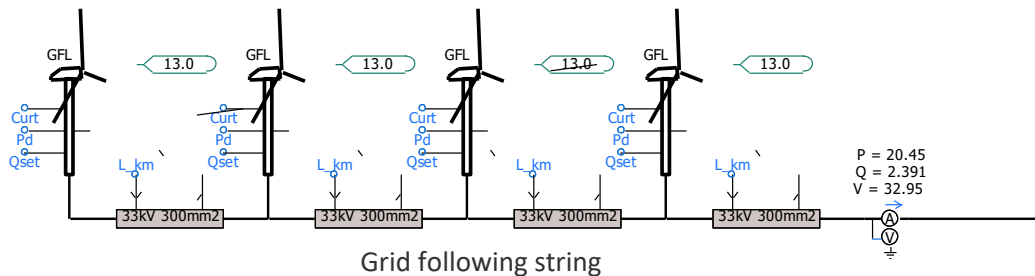
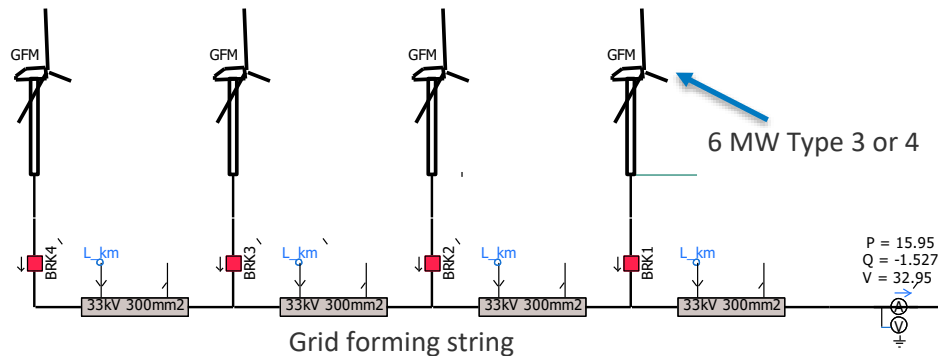
Collective full black start resource

Image source: NREL

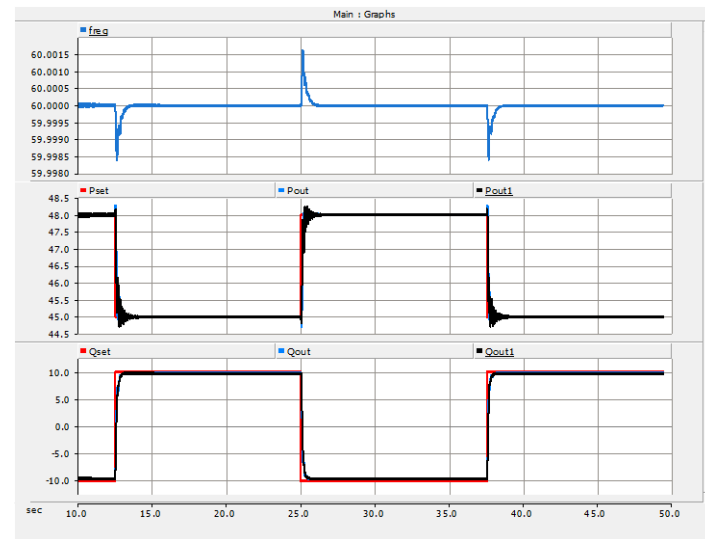
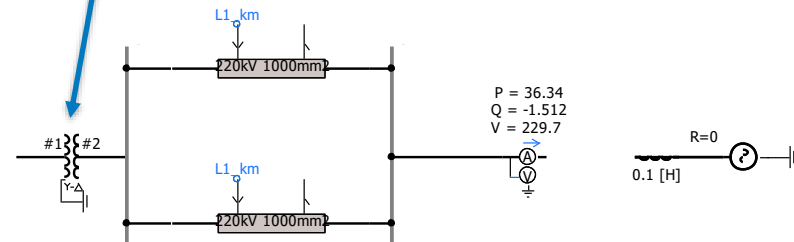
GFM IBRs for Black Start

- 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



Substation transformer



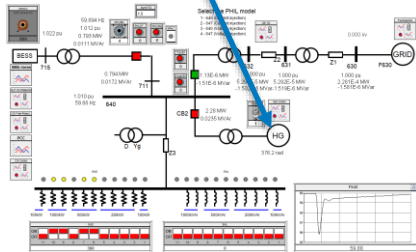
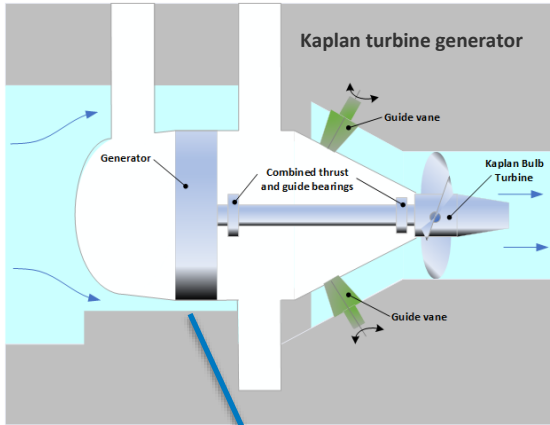
- NREL/GE demonstration using 2.x MW GFM WTG in 2021

Black-start using ROR Hydro Power Plant

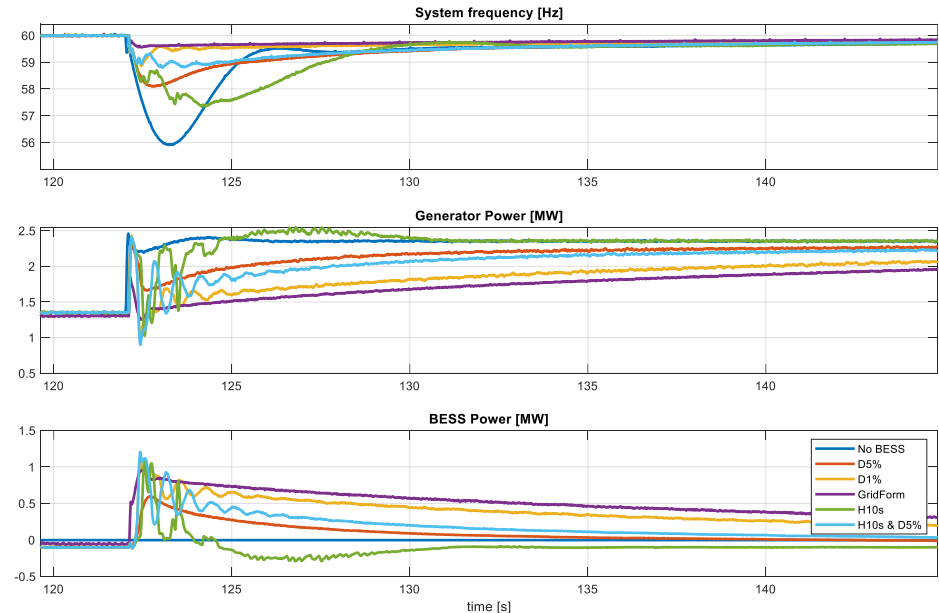
DOE WPTO funded INL/NREL/ANL project

PHIL Implementation of ROR Kaplan turbine generator operating with real BESS

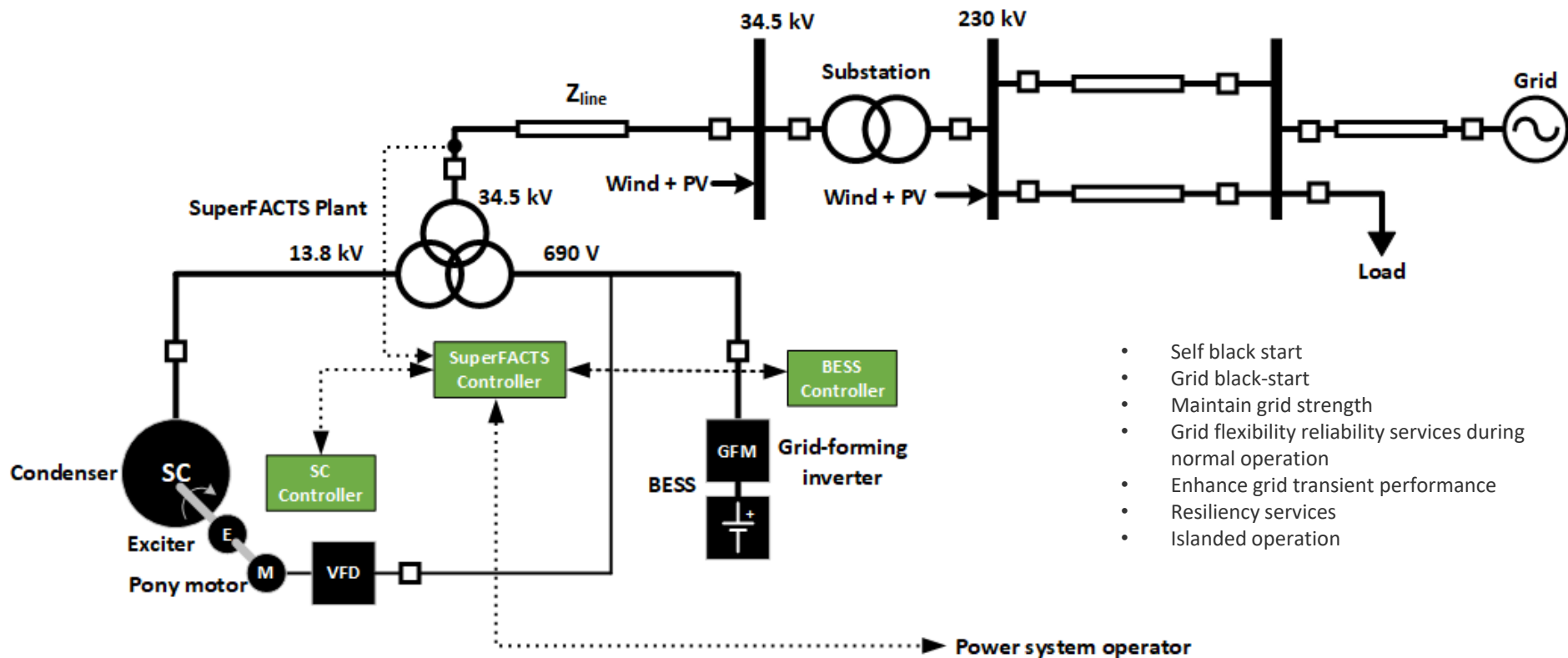
- April 2021 - field demonstration with Idaho Falls Power using 8 MW ROR HPP on Snake River in April/May 2021
- INL ultracapacitor energy storage



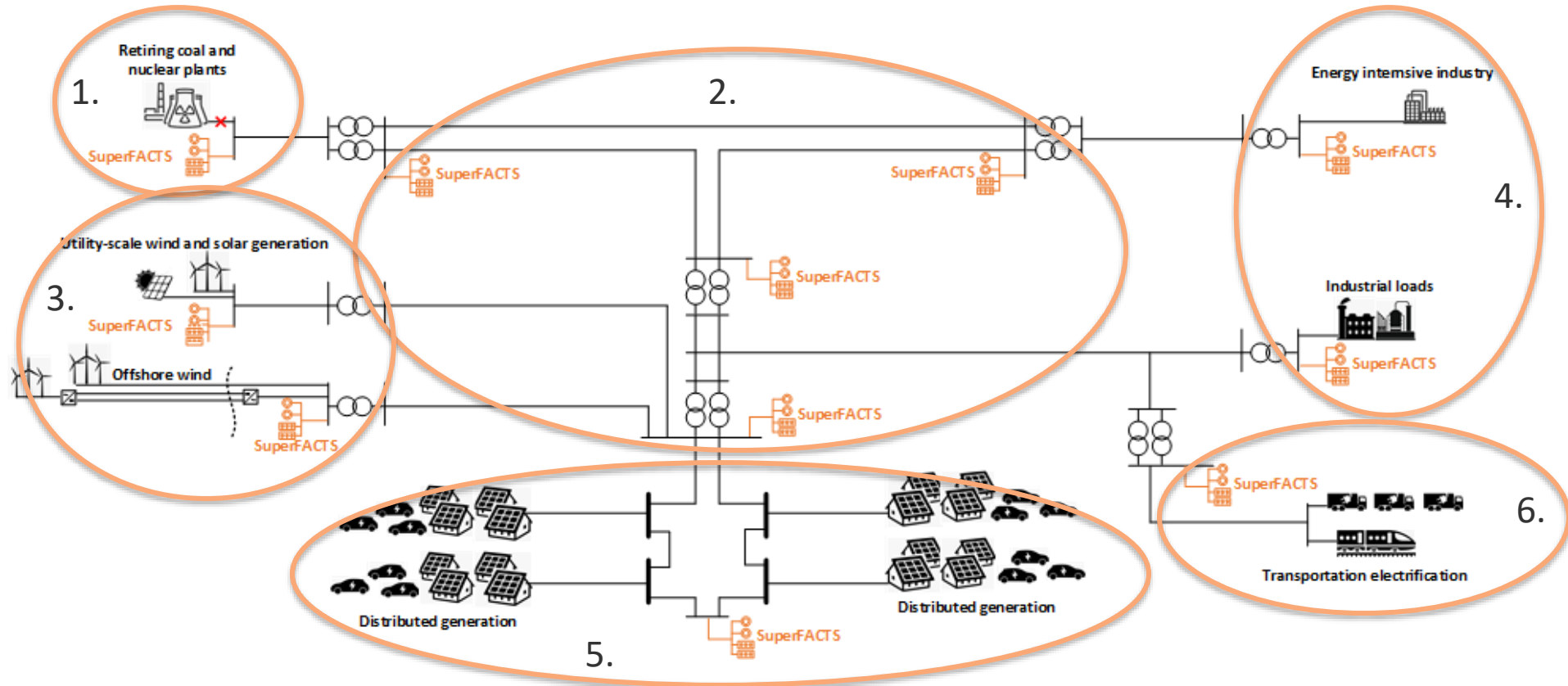
PHIL emulation of different strategies for ROR HPP black start



SuperFACTS Conceptual Diagram

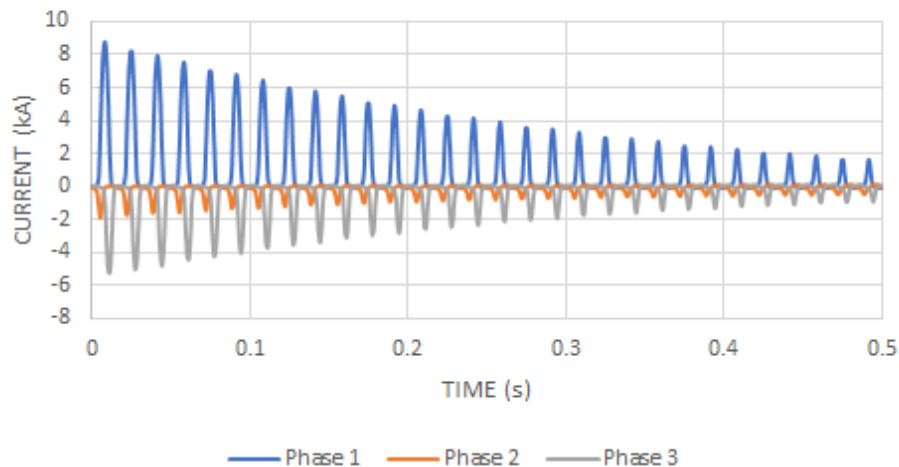


SuperFACTS Use Cases

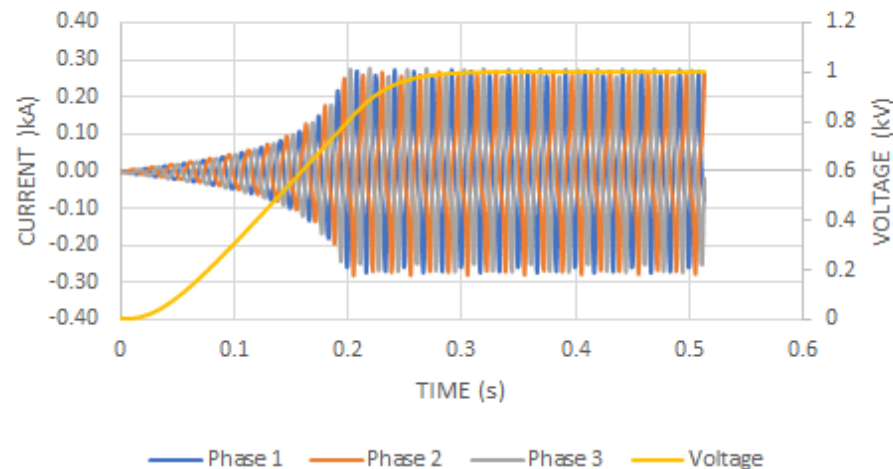


Transformer Energizing with GFM BESS – Soft Start

Transformer inrush currents - hard start

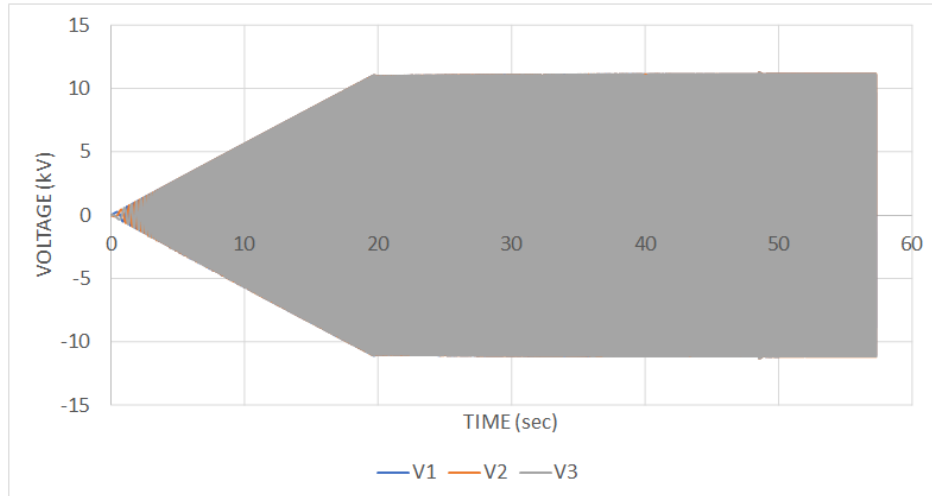
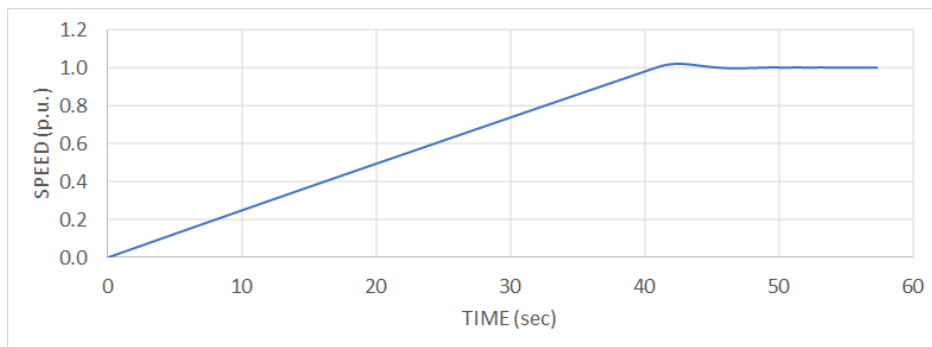


Transformer inrush current - voltage ramp



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

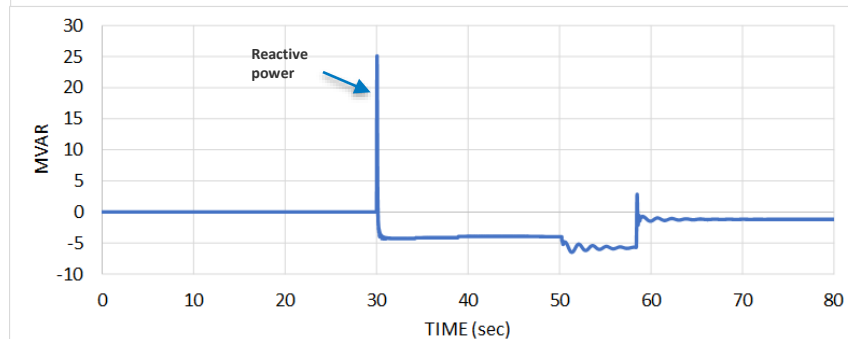
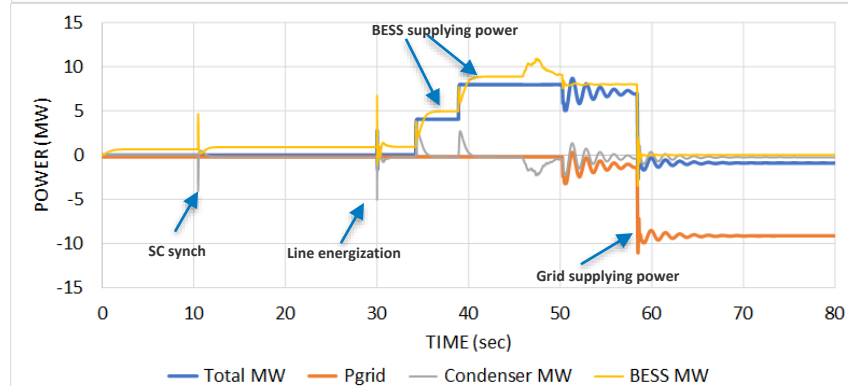
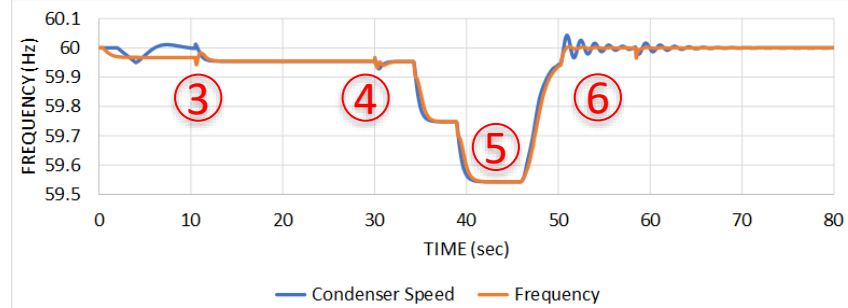
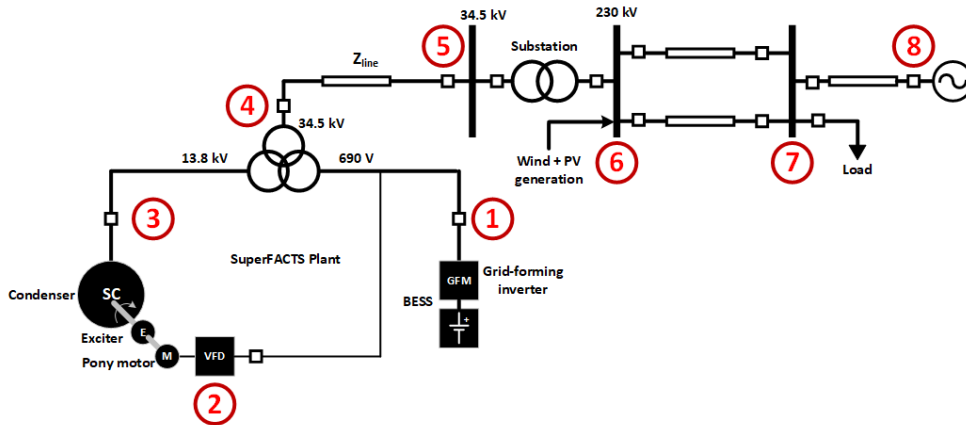
Synchronous Condenser Acceleration with Pony Motor



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

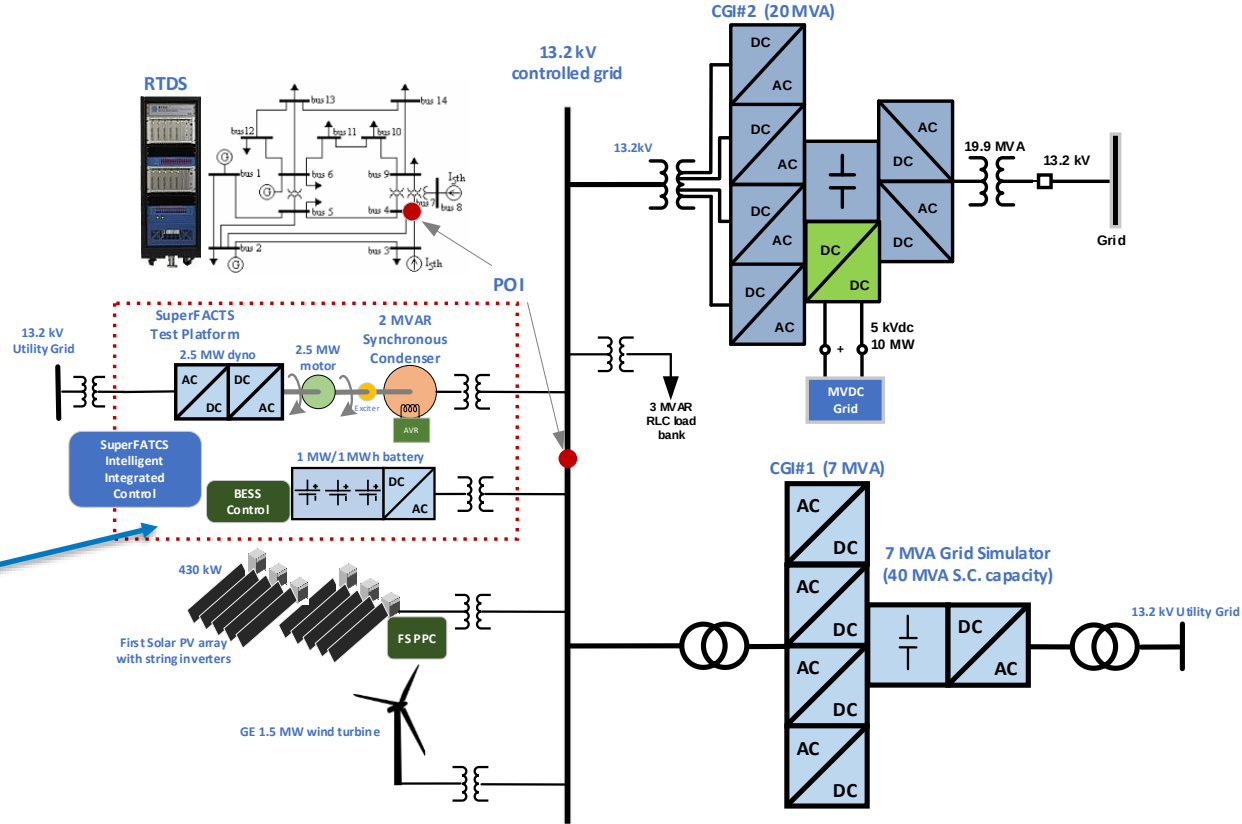
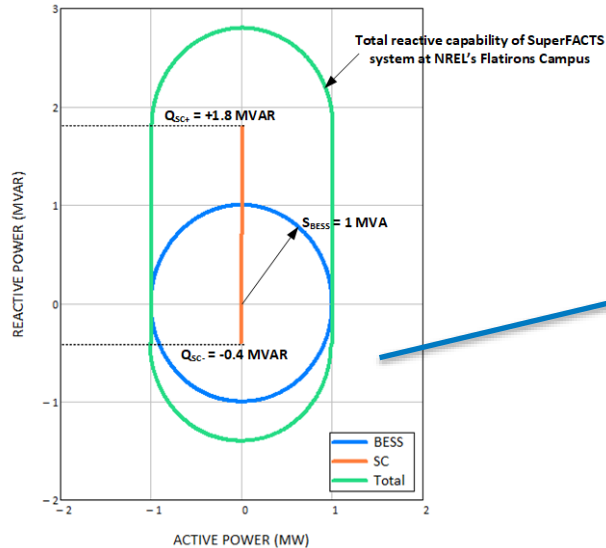
Black start use case

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



SuperFACTS Test Platform

Projected P-Q capability of SuperFACTS platform



Source: NREL

Microgrid Operation at NREL Flatirons Campus

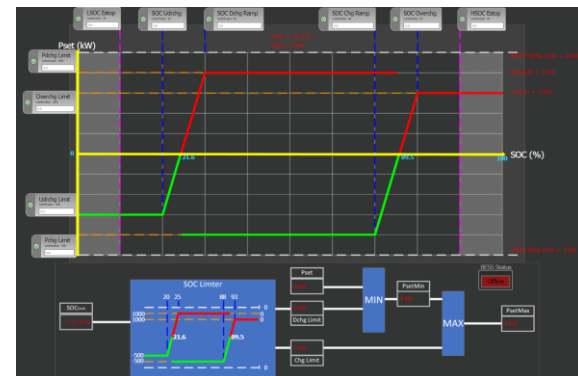


Image by Josh Bauer, NREL

Image from Flatirons Campus meteorology research tower camera

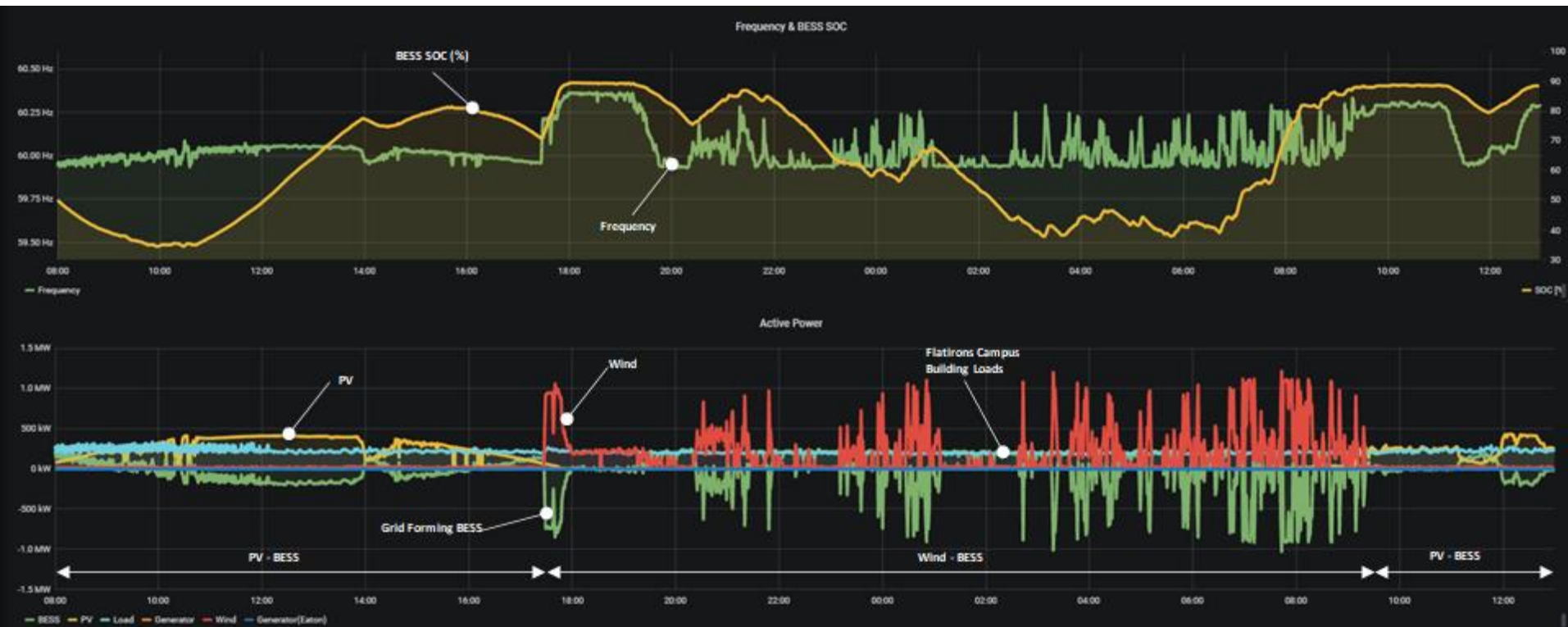


- GFM BESS controls; f-P and V-Q droop, additions P-SOC droop
- Black start controls GFM BESS (SMA inverter)
- Using frequency to control variable generation and BESS SOC



- 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

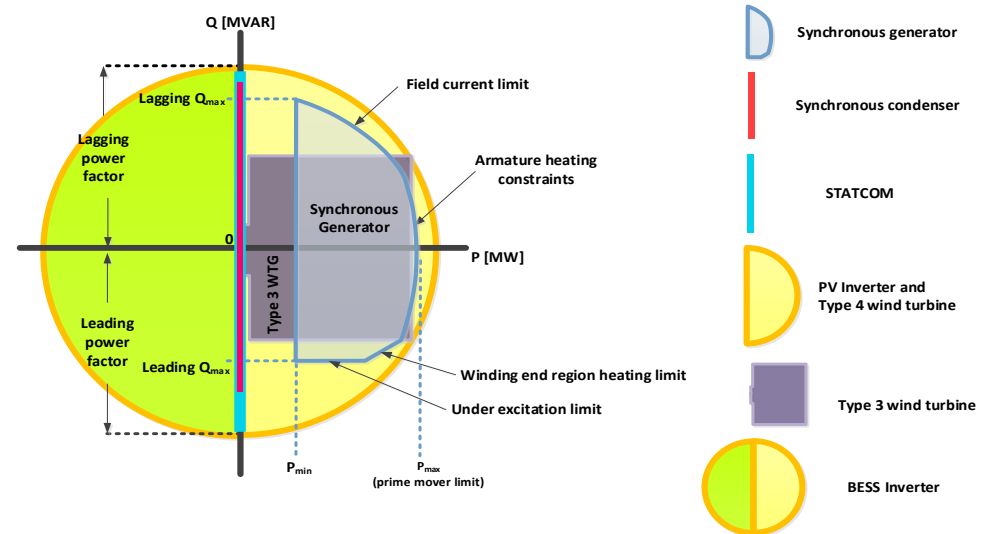


Image source: NREL

Thank you

www.nrel.gov

Vahan.Gevorgian@nrel.gov

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, and Office of Electricity. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

