Black start of Renewable Plants with Battery Grid Forming Inverters

V. Gevorgian, S. Shah, P. Koralewicz, R. Wallen

ESIG Spring Workshop

Albuquerque, NM

March 21, 2019

Black start Resources

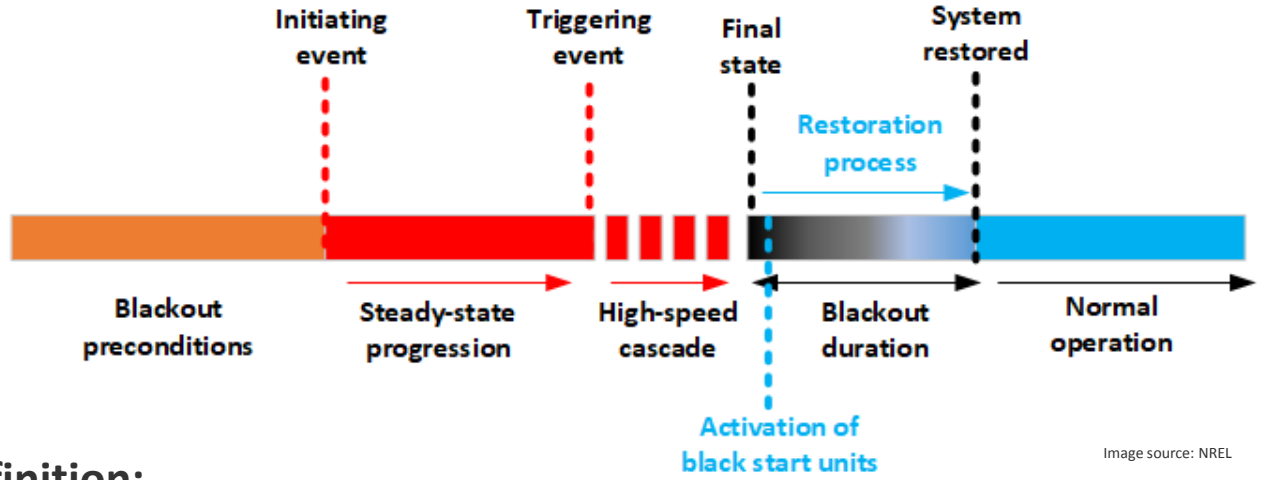


Image source: NREL

NERC definition:

"A generating unit(s) and its associated set of equipment which has the ability to be started without support from the System or is designed to remain energized without connection to the remainder of the System, with the ability to energize a bus, meeting the Transmission Operator's restoration plan needs for Real and Reactive Power capability, frequency and voltage control, and that has been included in the Transmission Operator's restoration plan"

Black Start Stages

The black start process can be divided into three stages:

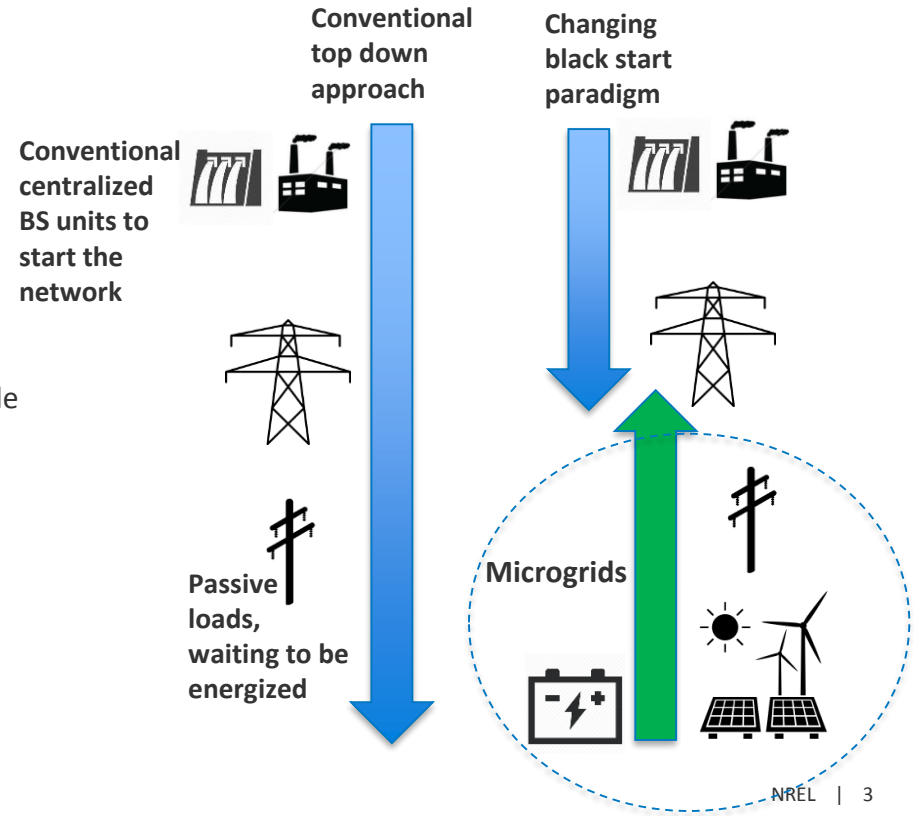
- **Preparation stage**
- **Network reconfiguring**
- **Load restoration**

A typical restoration plan for bulk power system includes the following essential steps:

- 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

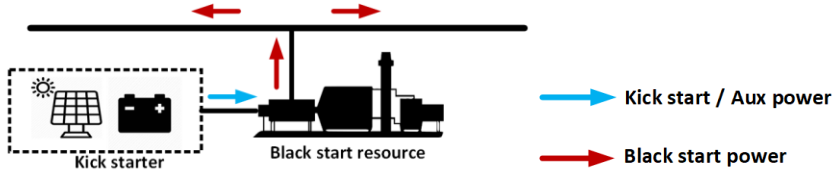
The restoration strategies:

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

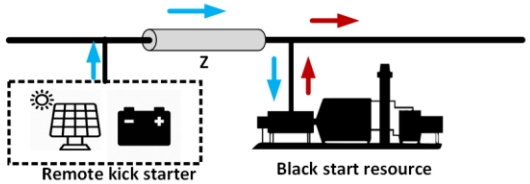


Configurations of Integrated PV/BESS Plants for Black Start

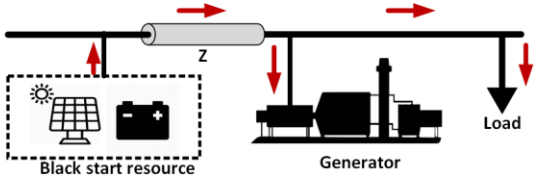
Co-located kick starter for black start resource



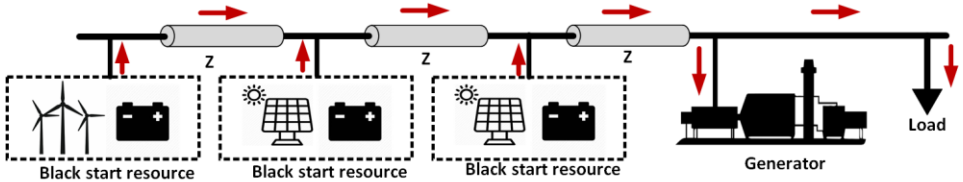
Remote kick starter for black start resource



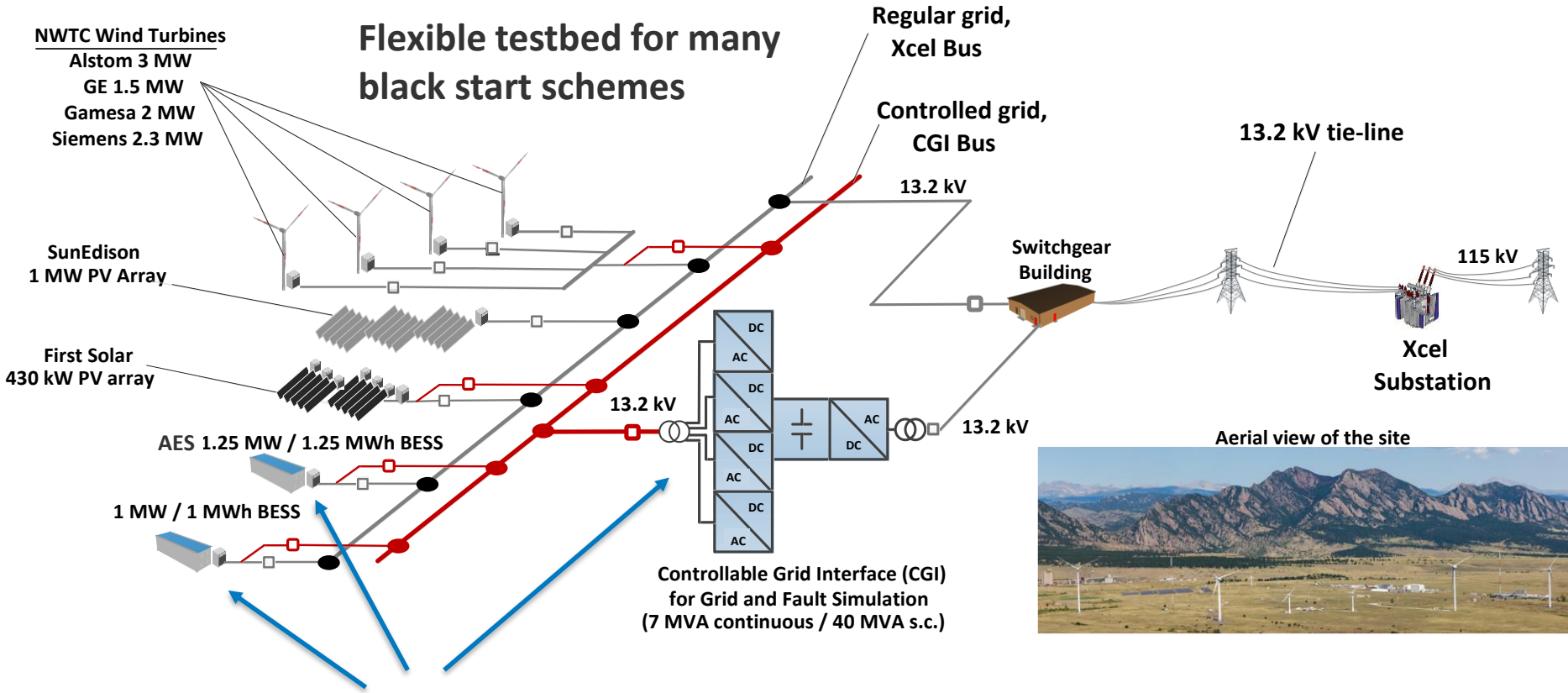
PV+storage as fully functional black start resource



Collective black start resource



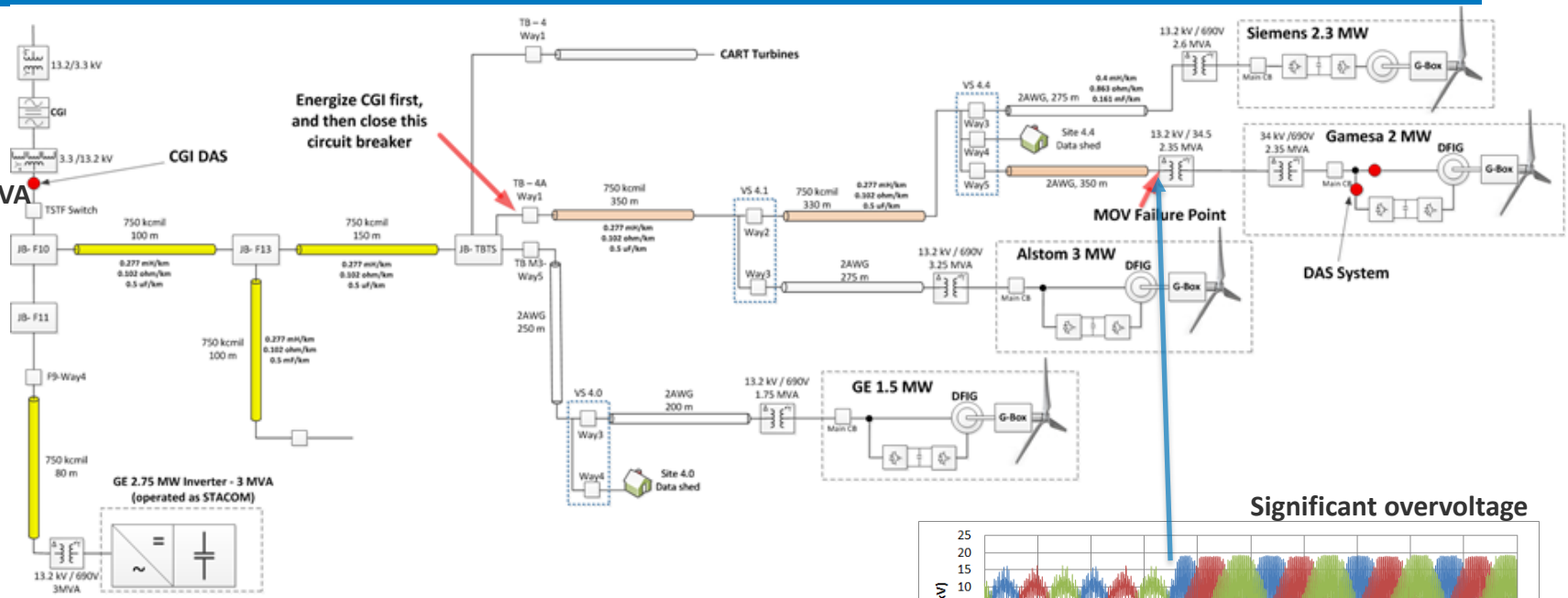
NWTC Controllable Grid Platform



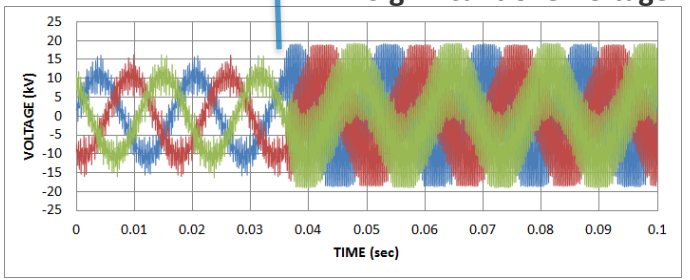
Aerial view of the site

Black-start of Wind Power Plant (13.2 kV system)

Grid forming inverter – 7 MVA



Significant overvoltage



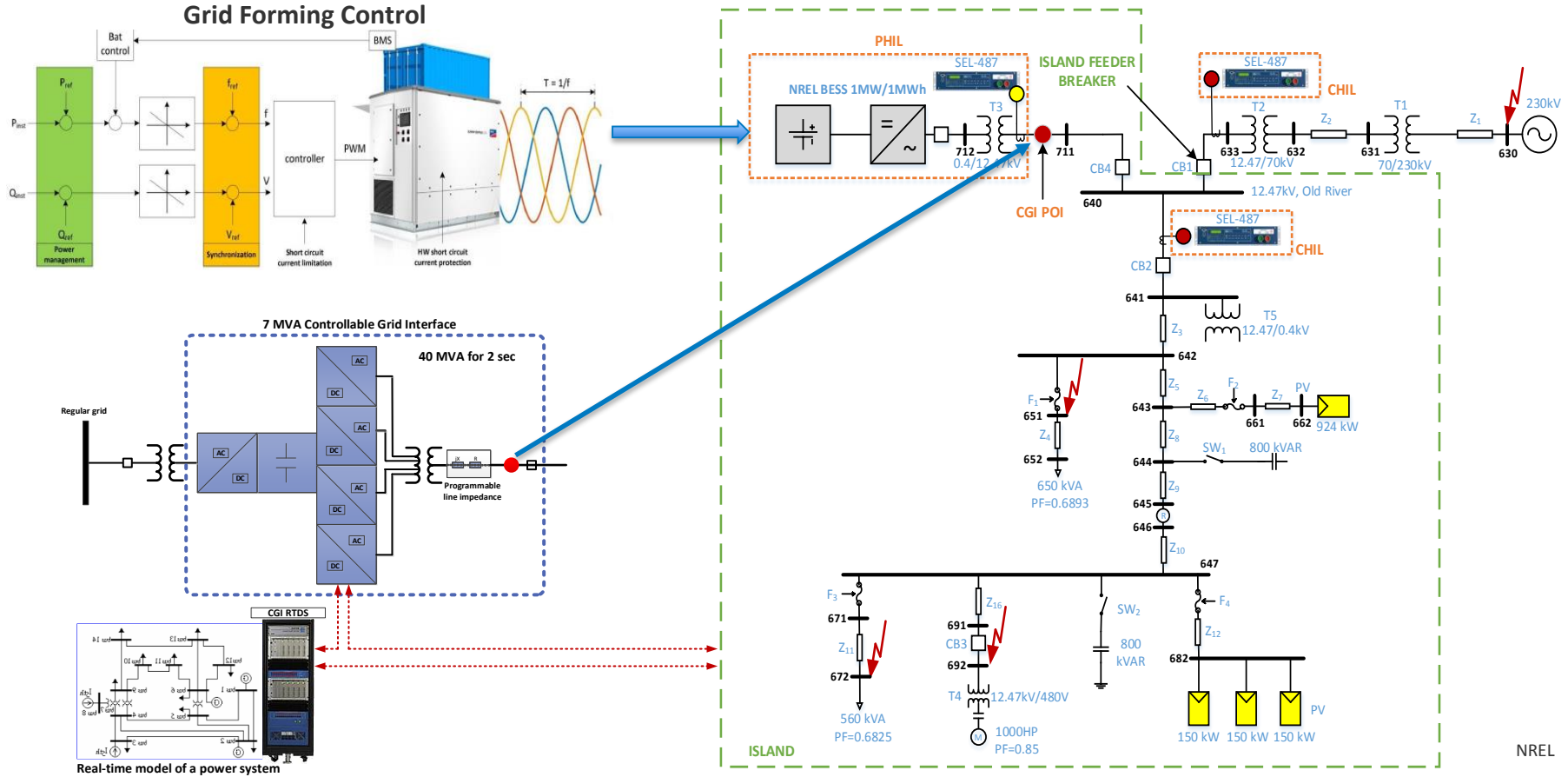
Main problems:

- Harmonics / resonances
- Grounding / protection
- Inrush currents

Solutions:

- Additional filtering
- Transformer neutral point grounding resistor
- Grounding transformers
- Oversized inverter (40 MVA SC capability)

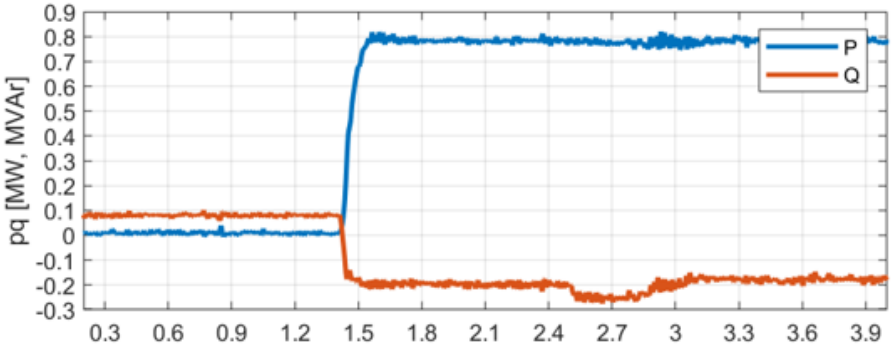
Distribution System Testbed for Islanded Testing



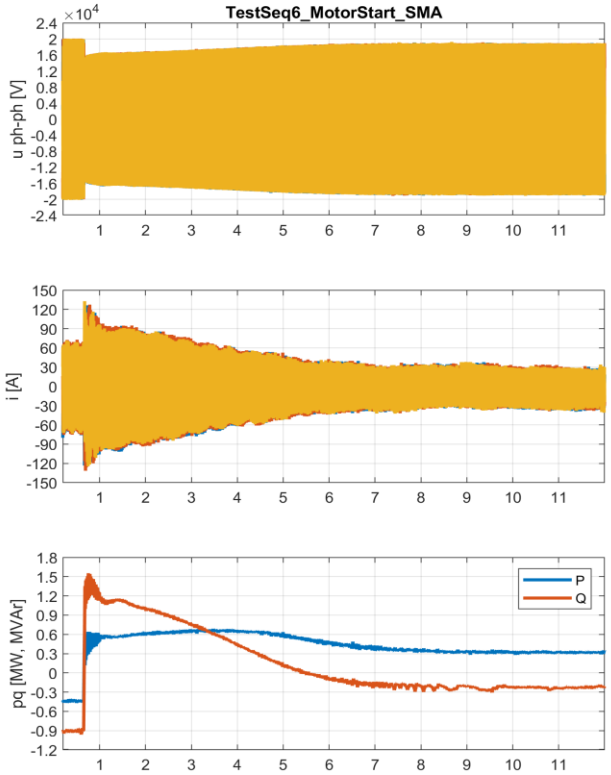
Distribution Circuit Restoration with BESS

PHIL testing results using 1 MW/1MWh BESS

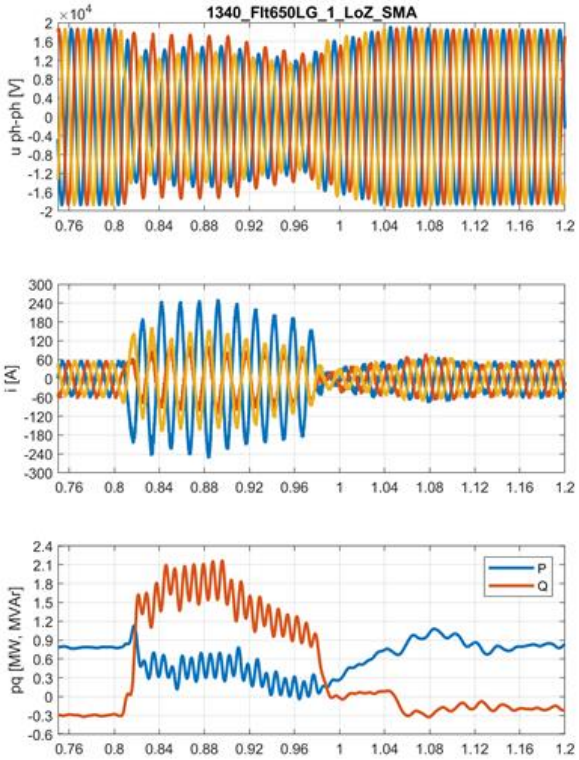
BESS Active and Reactive Power
in Grid Forming Mode

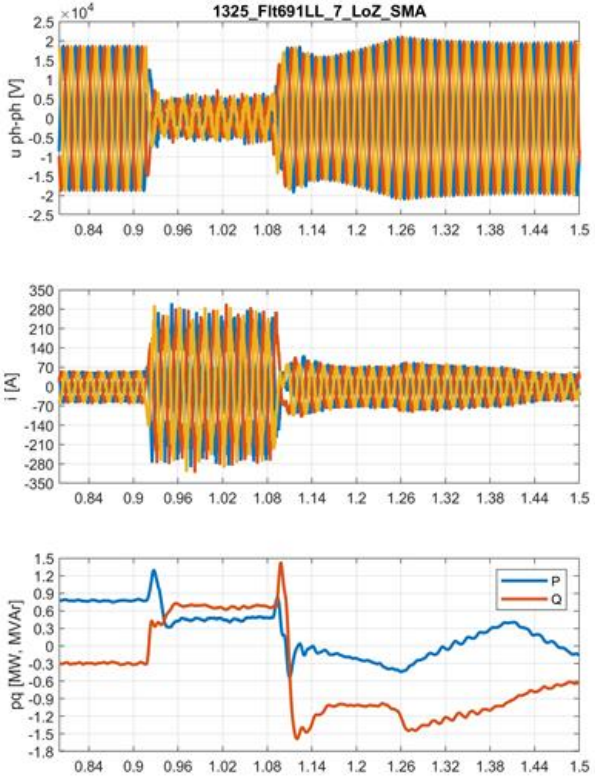


Motor start event

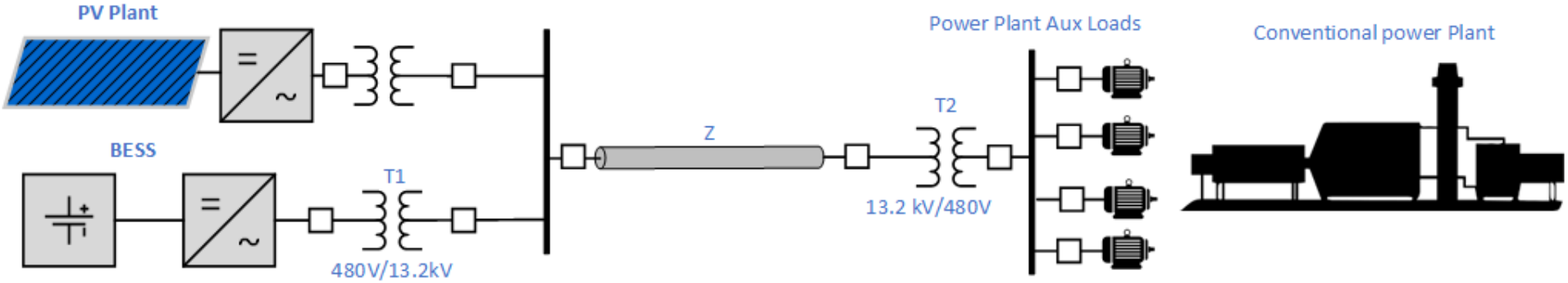


Fault-ride Through in Grid Forming Mode





PV-BESS Black starting a Gas Turbine Generator



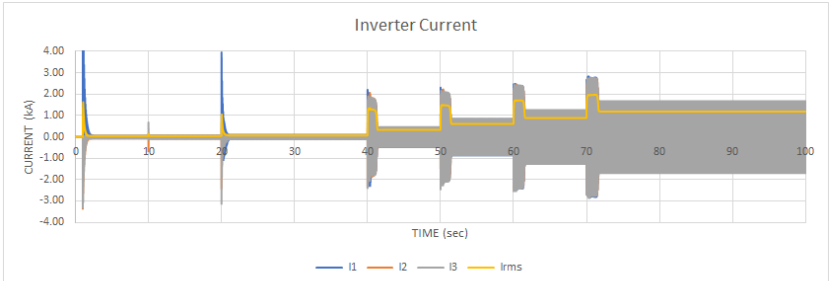
Main challenge:

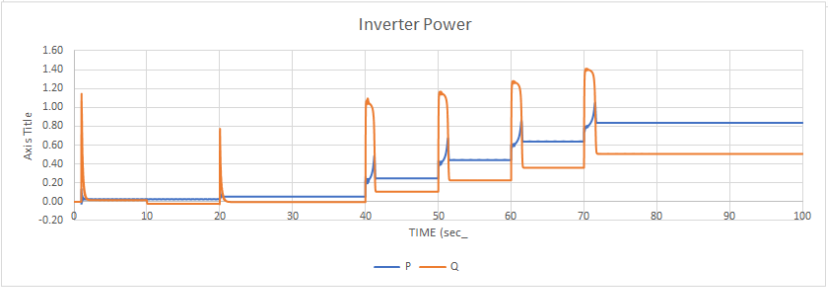
- Energizing transformers and feeders
- Mid-size gas turbines employ starting motors
- Black start inverters need to be sized to provide necessary inrush current

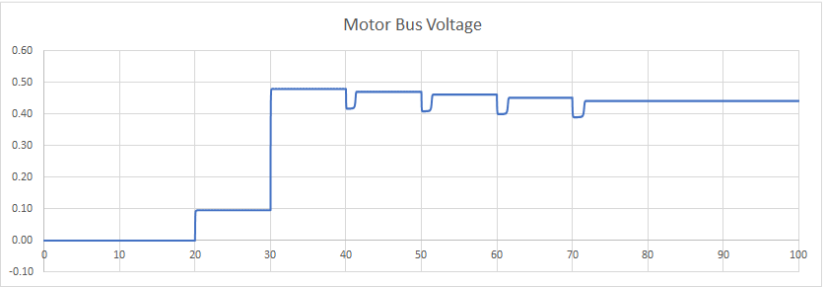
Possible solutions:

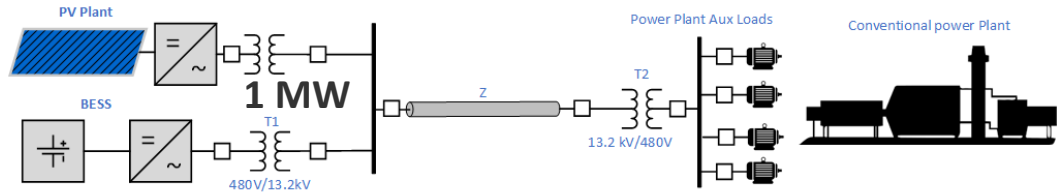
- Oversized inverters for inrush current
- Equip all plant motor loads with soft starters of VFDs
- Partial solution – energize transformers with tap positions at highest number of turns

Consecutive Start of Motors

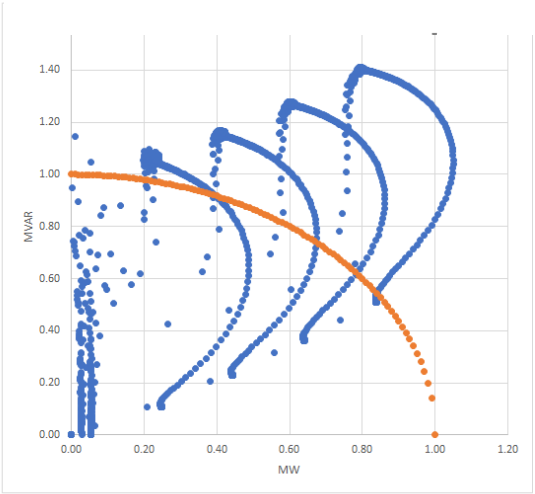




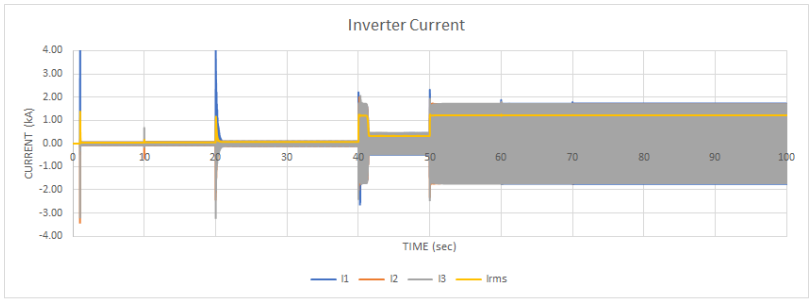


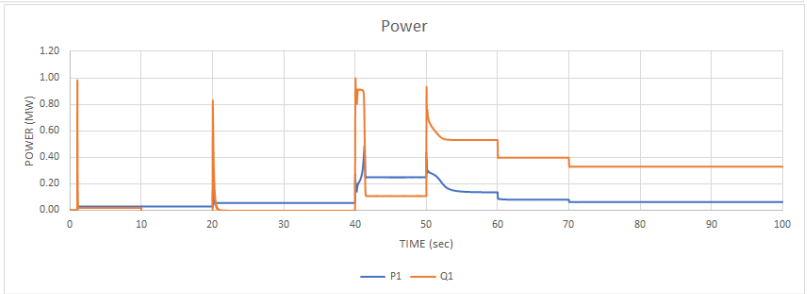


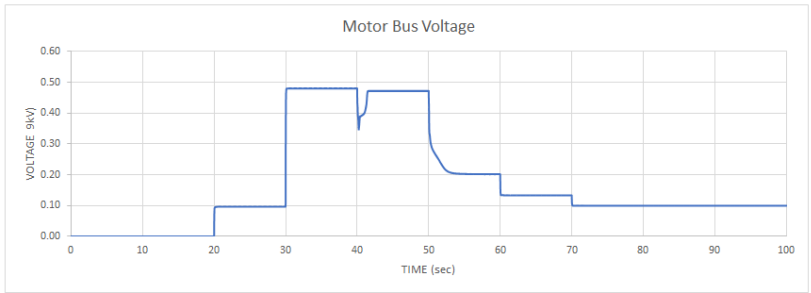
4x250 kW

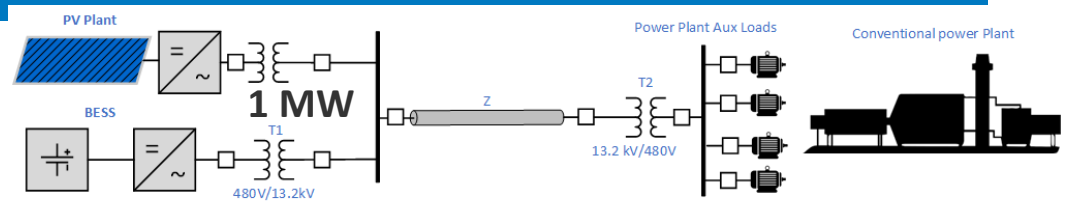


Inverters in Current limiting Mode

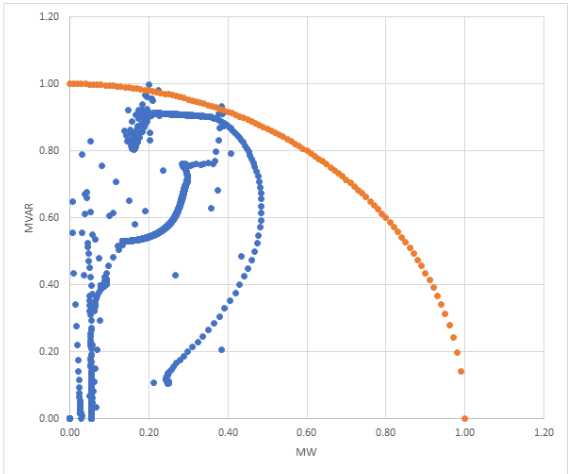






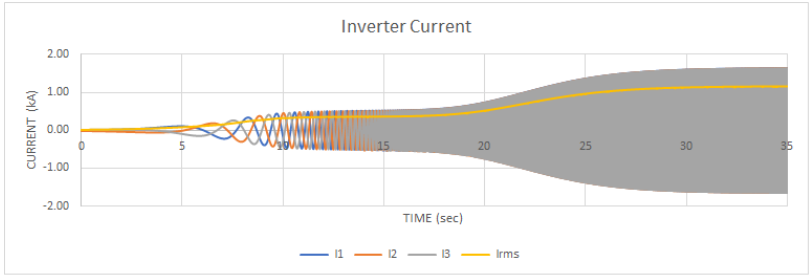


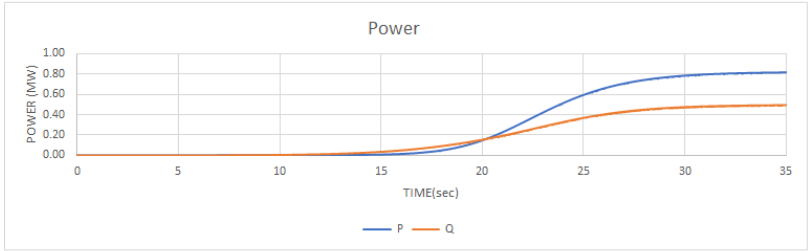
4x250 kW

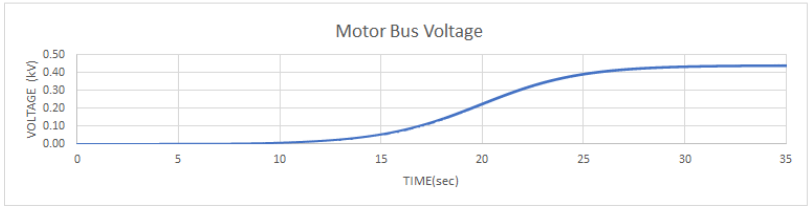


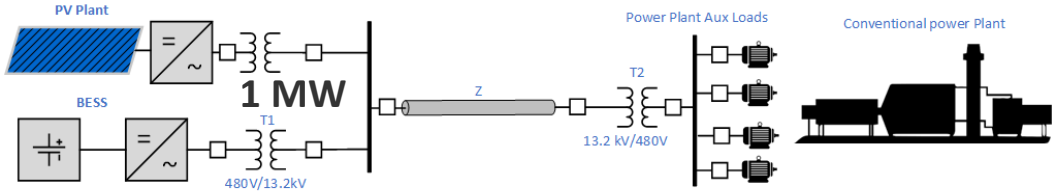
Constant V/Hz Soft Start

Inverters operate as VFDs with constant V/Hz ratio

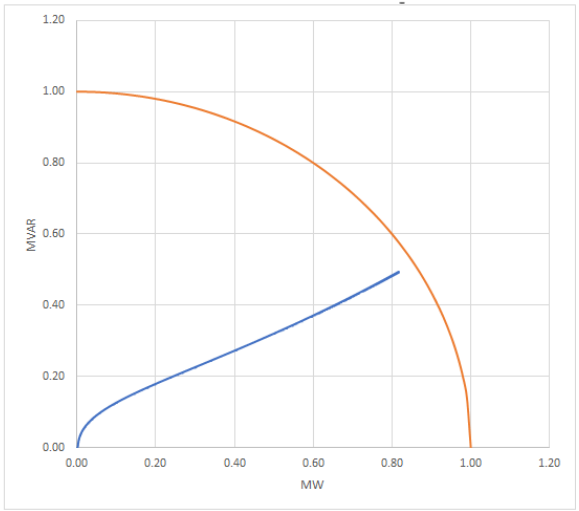






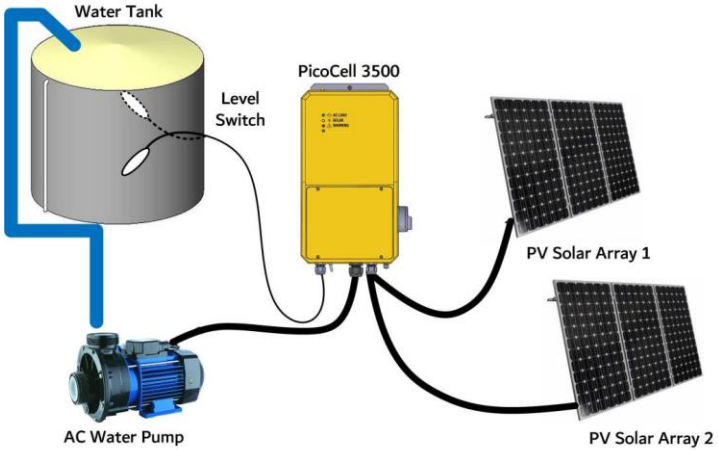


4x250 kW



- No overcurrent conditions during energizing/start up
- No need to oversize inverters

PV Inverter + VFD functionality



Source: SunTechDrive

- **Off-grid solar PV water pump – 3phase**
- **Over-current, over-voltage and over temperature protection**
- **Implemented in 1-3 HP systems**

- Solar MPPT control combined with VFD function
- Motor soft starting
- Matches solar output and motor loading
- Extends useful pumping time

Start-up of a DFIG-Based ROR Plant

DFIG with Inner Current Control Loops

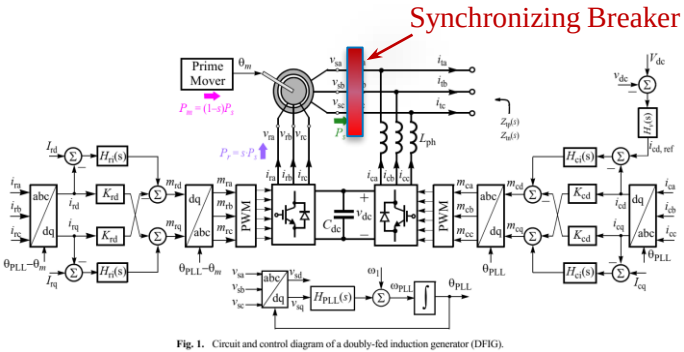
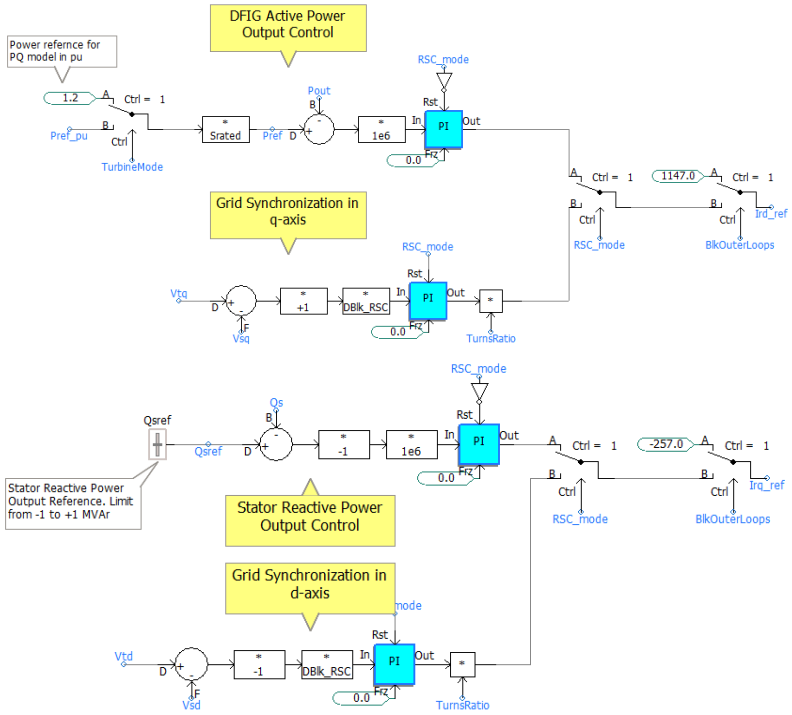
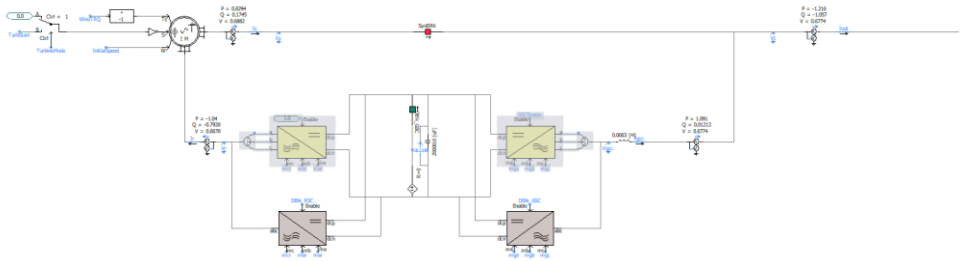


Fig. 1. Circuit and control diagram of a doubly-fed induction generator (DFIG).

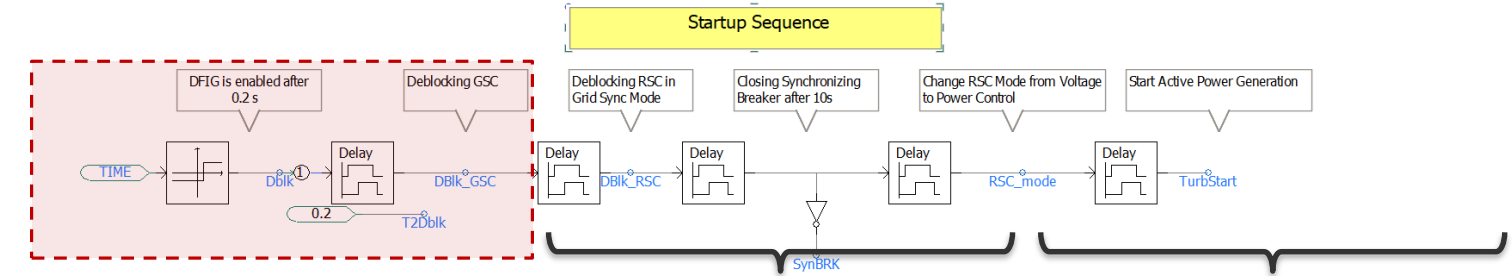
Grid Synchronization and Power Control Modes



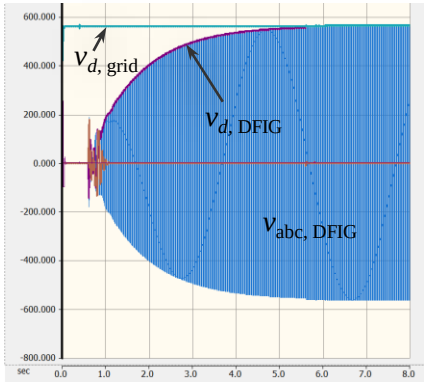
PSCAD Model for Start-up

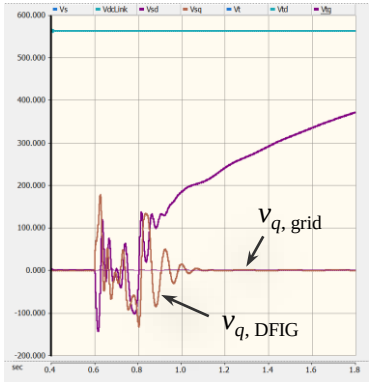


Startup Sequence



Grid Synchronization

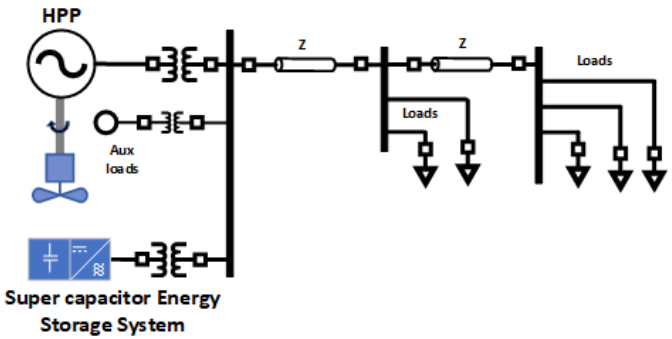




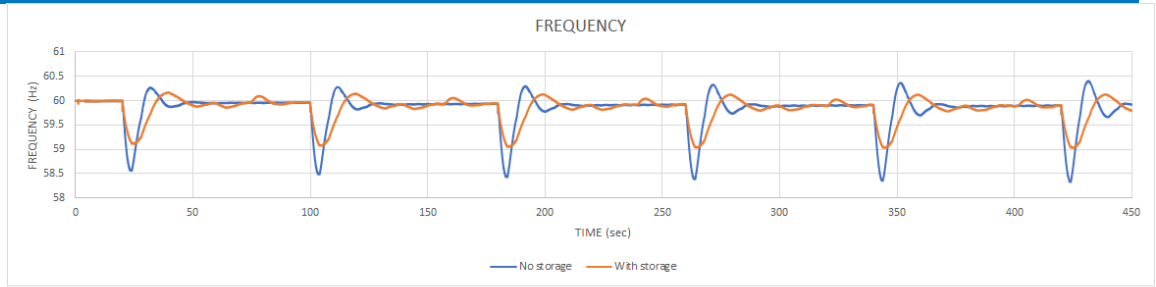
Summary

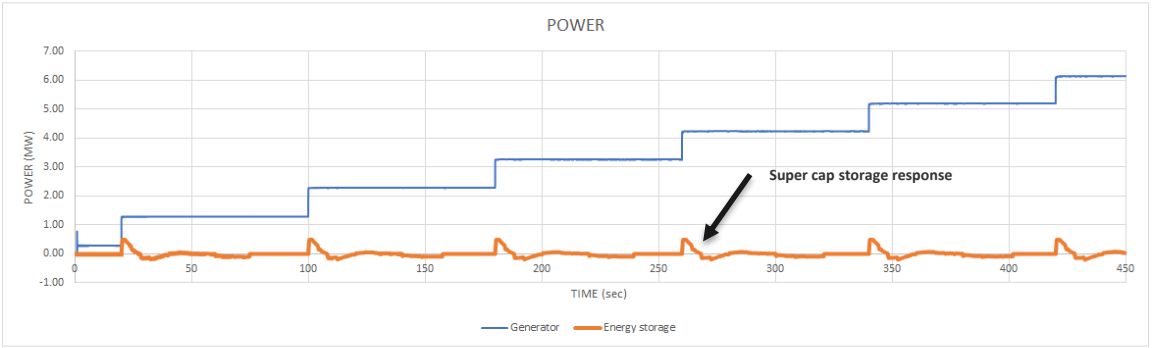
- Grid synchronization by locking dq frames of DFIG and grid, and matching stator voltages with grid voltages
- Further Work
  - Implementation of dc-bus control using storage for black-start
  - Coordination of multiple units – grid-forming control

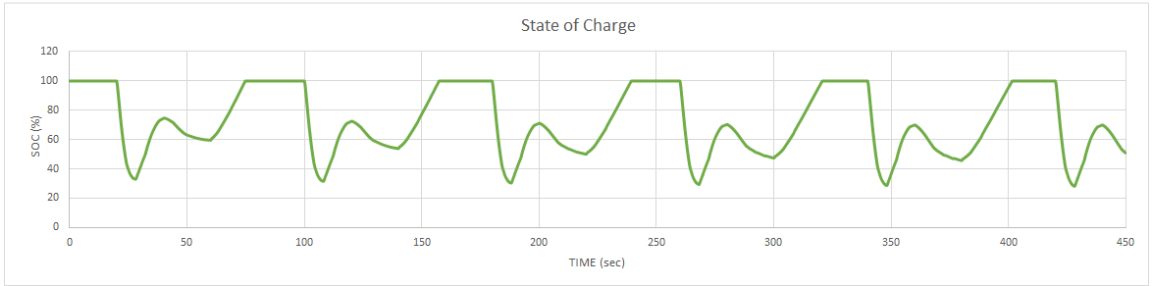
HPP / Ultracapacitor Energy Storage for Improved Restoration Process



- INL-NREL project
- Industry partners:
  - Idaho Falls Power
  - Siemens
  - Maxwell



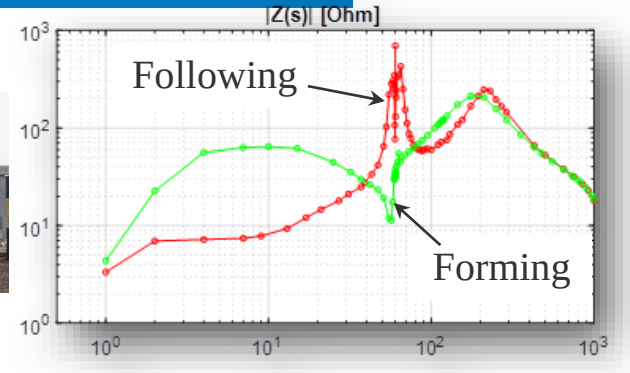




Grid-Forming Inverter from *Outside*

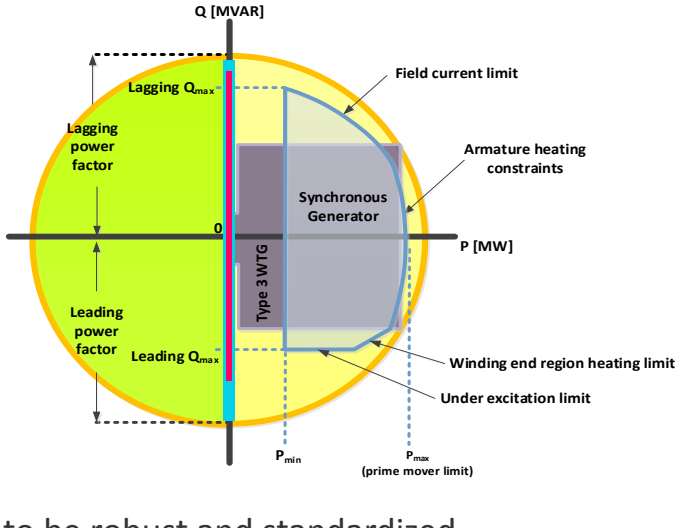
- BESS Inverter

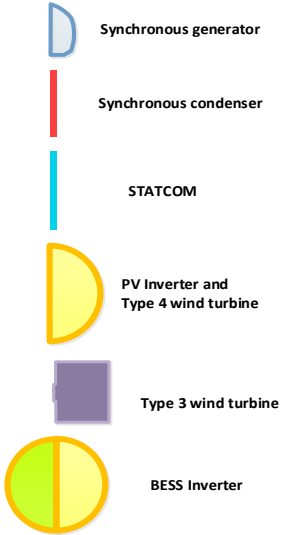
- Impedance measurements can **quantify** different aspects of grid-forming ability



Conclusions

- 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 inverter current limit is one most important factor for black start applications





Recommendations

- Fault performance of grid forming inverters – needs to be robust and standardized
- Seamless transition between grid forming and grid following is important, but do we really need grid following mode?
- Impedance characterization of grid forming inverters
- Grid stability impacts of grid forming
- Validated grid forming inverter models are needed for various renewable and storage technologies for successful black start studies
- At scale PHIL testing of black start-capable renewable resources is an important tool to discover potential issues, test mitigating solutions and validate models

Thank you

www.nrel.gov

Publication Number

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 Solar and Wind Energy Technologies Offices. 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.