OAK RIDGE National Laboratory

Grid Forming Battery Energy Storage System for Black Start Studies

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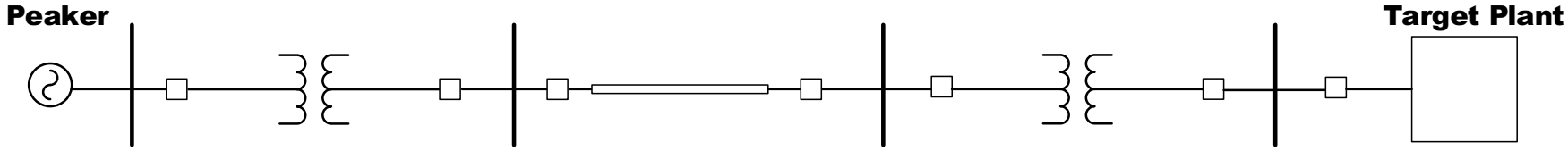
U.S. DEPARTMENT OF ENERGY

Introduction

- Blackouts,
- Typical initial causes of cascading outages and blackouts,
- Major blackouts,
- Restoration approach (bottom-up vs top-down restoration),
- Peakers, target units, and cranking paths,
- System restoration procedures,
- Roles of responsibilities of ISO, GCC, and Switching Centers during the black start.



NERC Definitions

- NERC's definition of the Blackstart Resource: 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.
- NERC's definition of the Cranking Path: A portion of the electric system that can be isolated and then energized to deliver electric power from a generation source to enable the startup of one or more other generating units.

SCE by the Numbers

- SCE operates five natural gas-fired peaker plants. Two of these peaker plants, use enhanced gas turbines, which operates a hybrid-battery system, which saves water.
- SCE's largest plant, Mountainview Generating Station, is a 1,104 MW efficient natural gas combined cycle resource.
- SCE's largest hydroelectric resource is Big Creek, located in the Sierra Nevada mountains.
- SCE's energy storage portfolio, installed or contracted, is more than 5,000 megawatts, maintaining it as one of the largest in the nation.

Challenges with Phasor-Domain Studies

- Switching transients, high-frequency overvoltages, during the black start system restoration should be studied in detail using EMT simulation, including energization of transformers, lightly loaded transmission lines, and energization of critical load,
- Resonance issues can occur when energizing a transformer, cables, and transmission lines,
- Steady state overvoltage (Ferranti effect),
- Presence of non-linear equipment and load leading to harmonic issues.

Challenges with Phasor-Domain Studies

- Model transformer inrush and saturation phenomenon, and remanent flux,
- Worse case scenario switching around zero-crossing of rising and falling edge of the voltage at gen-tie,
- Point-on Wave (POW) switching.

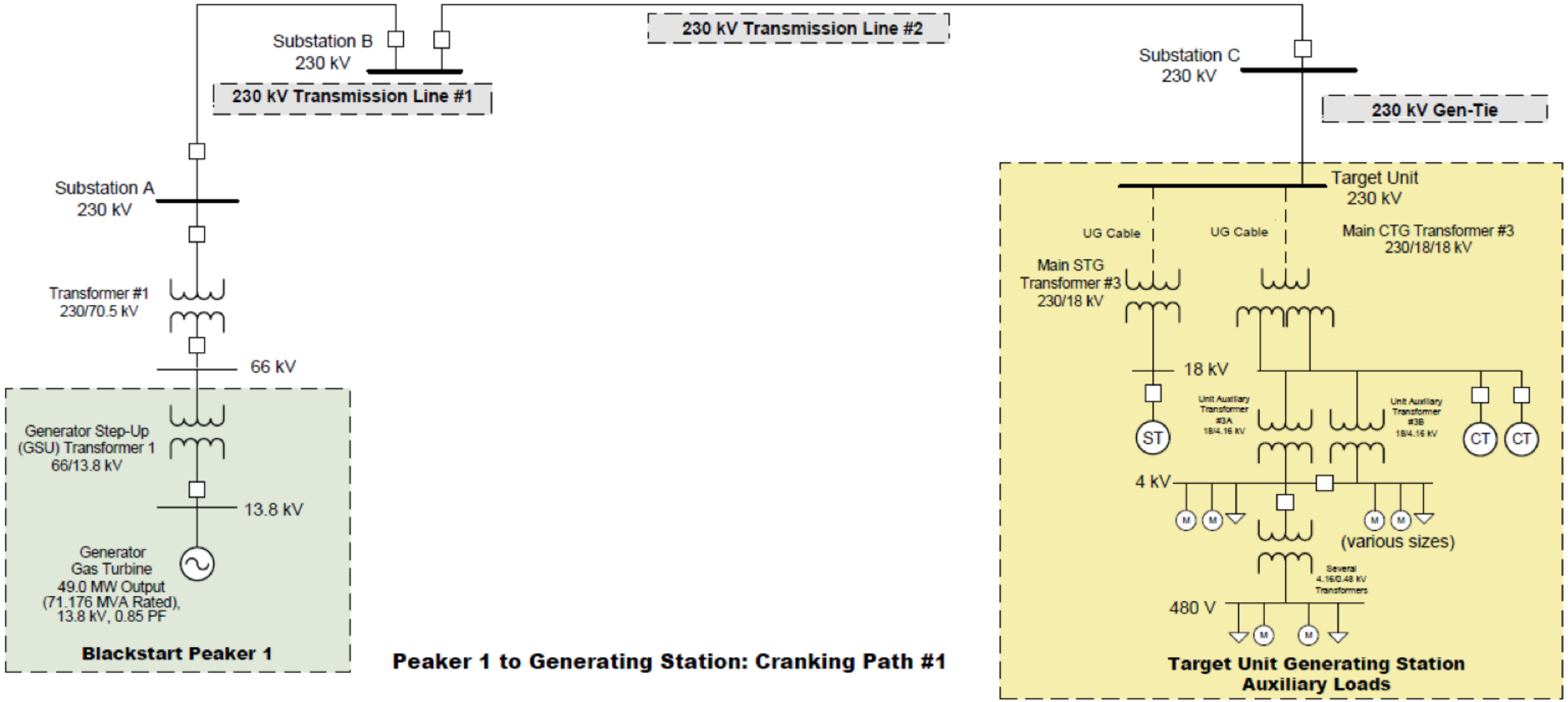
EMT Studies for Blackstart System Restorations

- NERC Standard EOP-005-3: System Restoration from Blackstart Resources,
- NERC Standard EOP-006-3: System Restoration Coordination,
- NERC Standard EOP-009 – Documentation of Blackstart Generating Unit Test Results.
- Restoration procedure field testing vs EMT simulation,
- The primary goal is to examine system limits (voltage and frequency) during the switching transients, peaker reactive limits during energization of the long lightly loaded transmission lines – charging current is high.

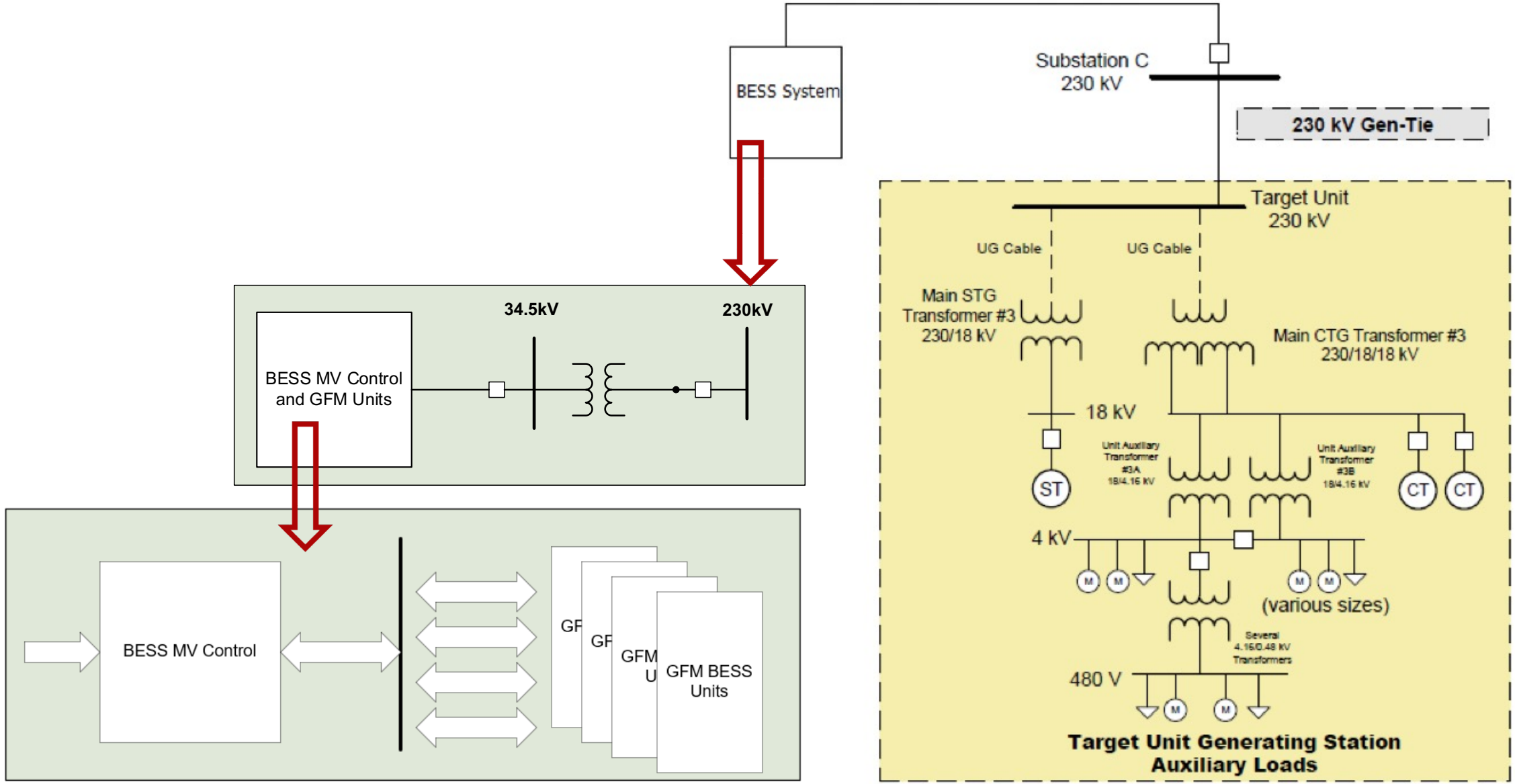
EMT Blackstart Studies

- Perform EMT simulation using existing synchronous generator as a peaker unit.
- Replace the peaker unit (LM6000) and cranking path with a gen-tied GFM BESS. The black-box PSCAD LCI and BESS models were provided by GE. The LCI model is the GE proprietary model based on field measurements.
- Perform PSCAD BESS model testing. Perform current and voltage harmonic impedance scan at the 230kV bus.
- Monitor system voltage, frequency, currents and power during each restoration step.
- Apply the criteria for system restoration studies.

EMT Models for Blackstart Studies



EMT Models for Blackstart Studies



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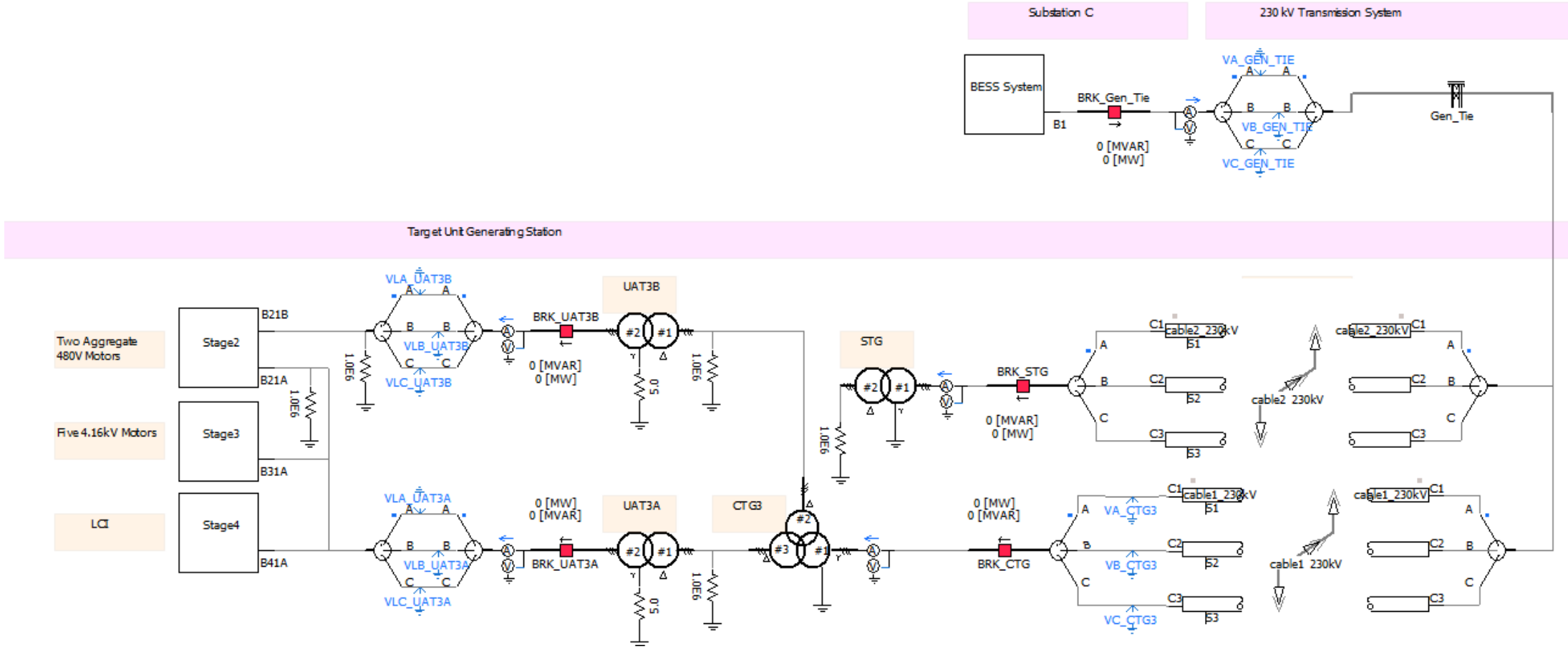
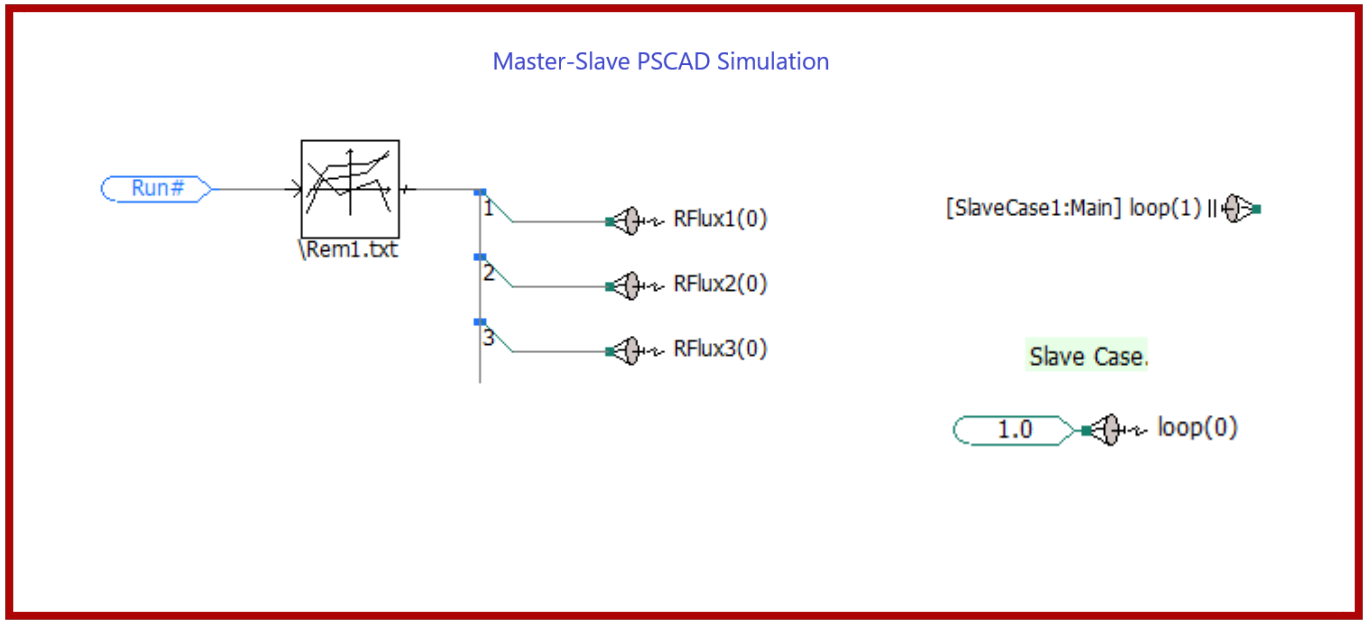
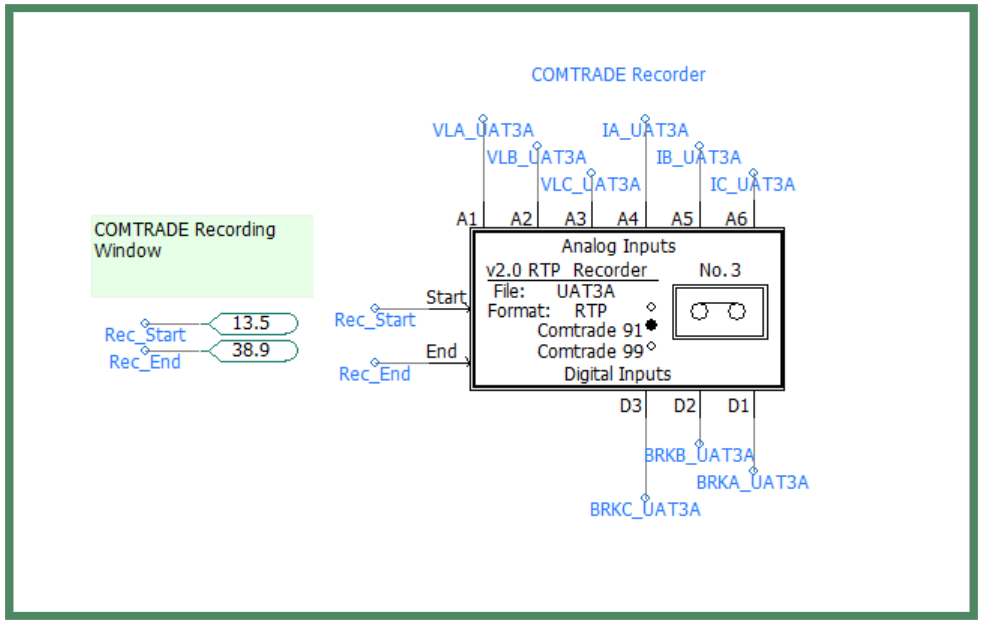
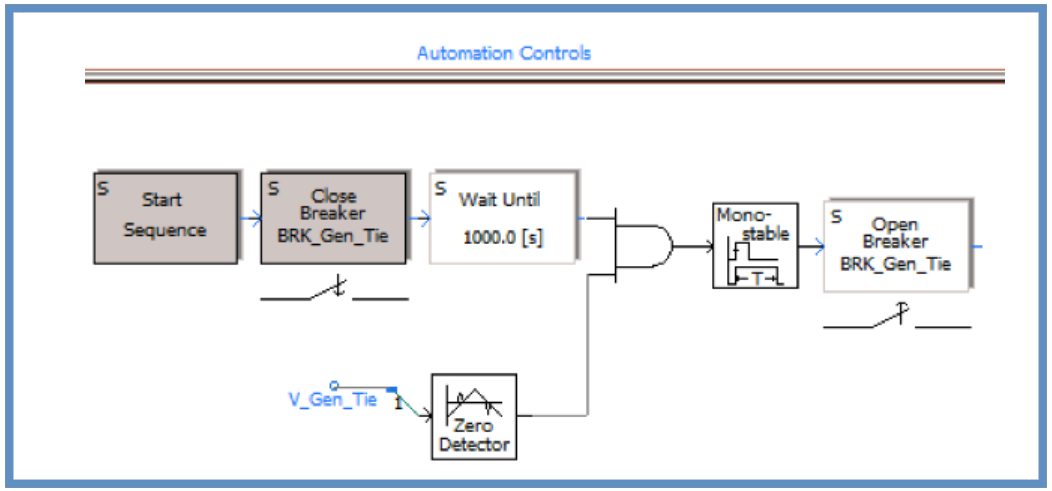
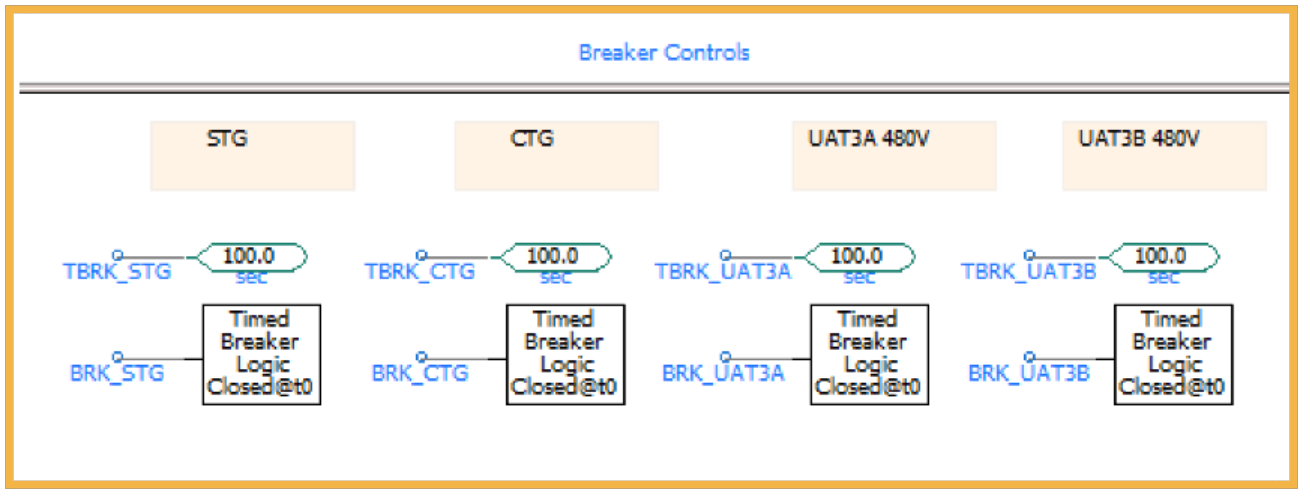


Blackstart Studies Breaker Control and Automation in PSCAD

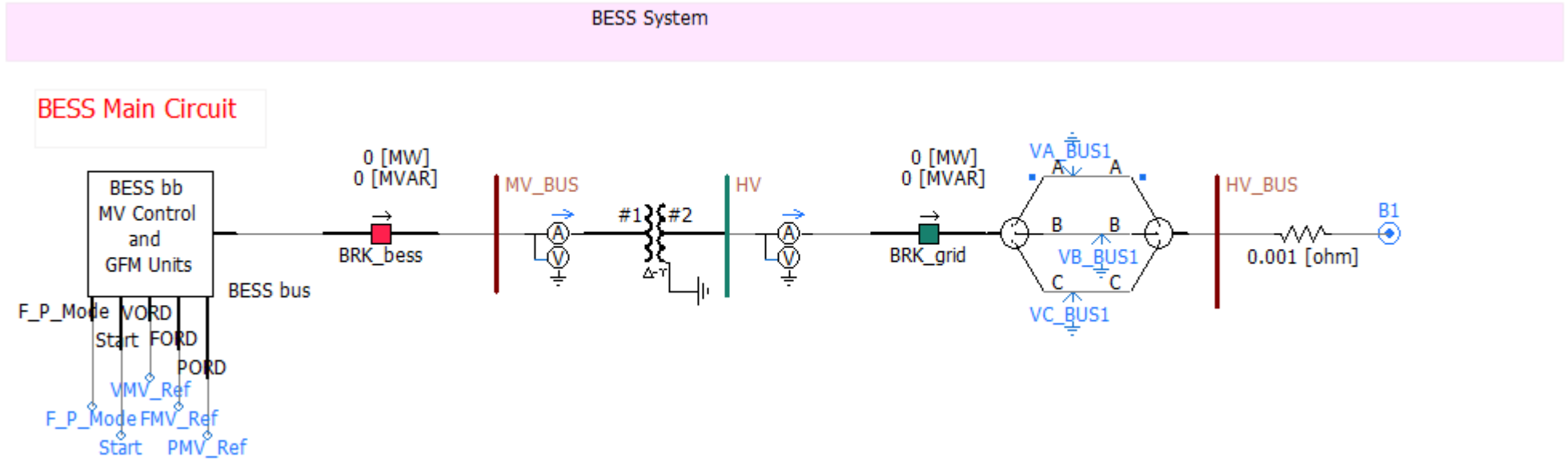








PSCAD BESS Component Parameters



Configuration

General	
System Frequency	60.0
Transformer MV winding rated voltage	34.5
Transformer leakage per unit reactance	
Transformer MVA base for reactance	
Number of Converters (N* MVA)	

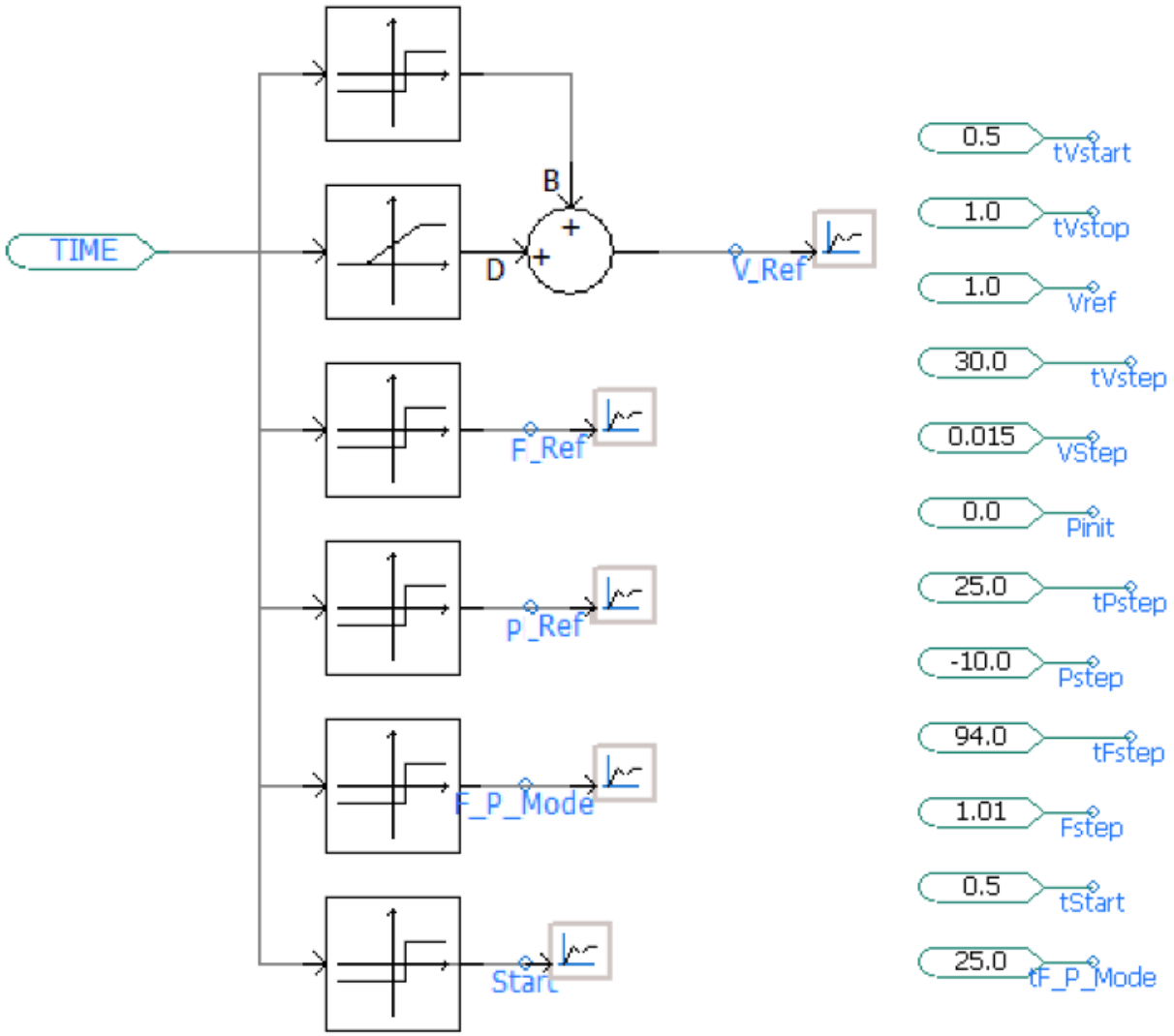
Regulator Parameters

General	
Power Regulator BW	
Voltage Regulator BW	
Voltage Droop Gain at MV Level	0.0
Frequency Droop Gain at MV Level	0.0
Power Droop Gain at MV Level	0.0

Internal Output Variables

GFM Unit	
PLVGFM	PLVGFM
QLVGFM	QLVGFM
VLVGFM	VLVGFM
FCNV	FCNV

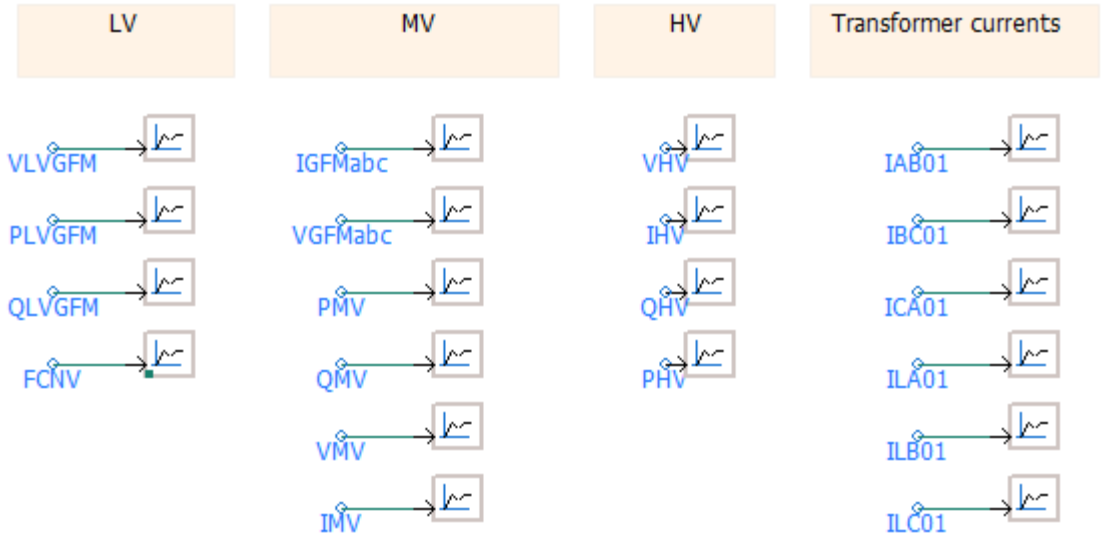
PSCAD BESS Model Inputs and Output



User-configured BESS commands issued to the BESS MV controller.

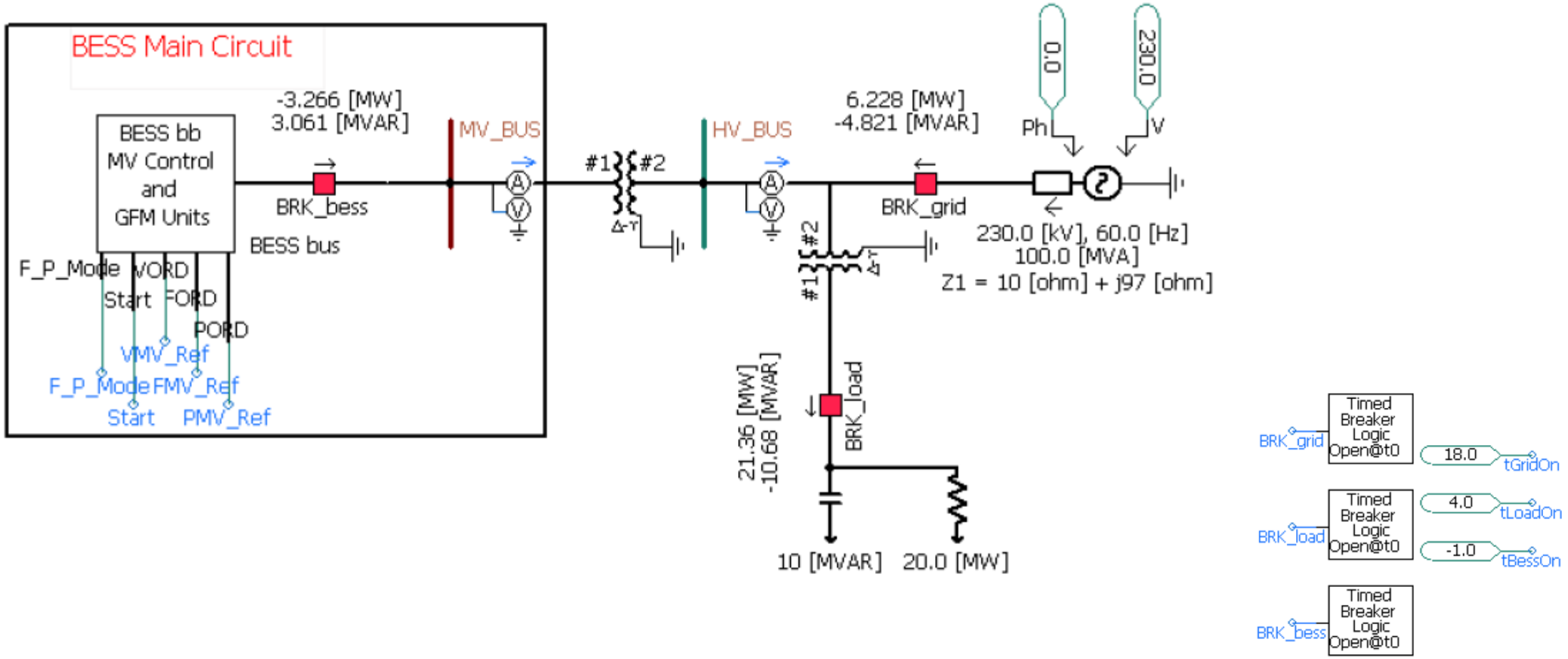
- V_ref - voltage
- F_Ref – frequency
- P_Ref – Real power
- F_P_Mode – BESS control mode (1- power regulation, 0 – frequency control for blackstart)
- Start – 0 – OFF, 1 – ON

PSCAD BESS Model Measured Output

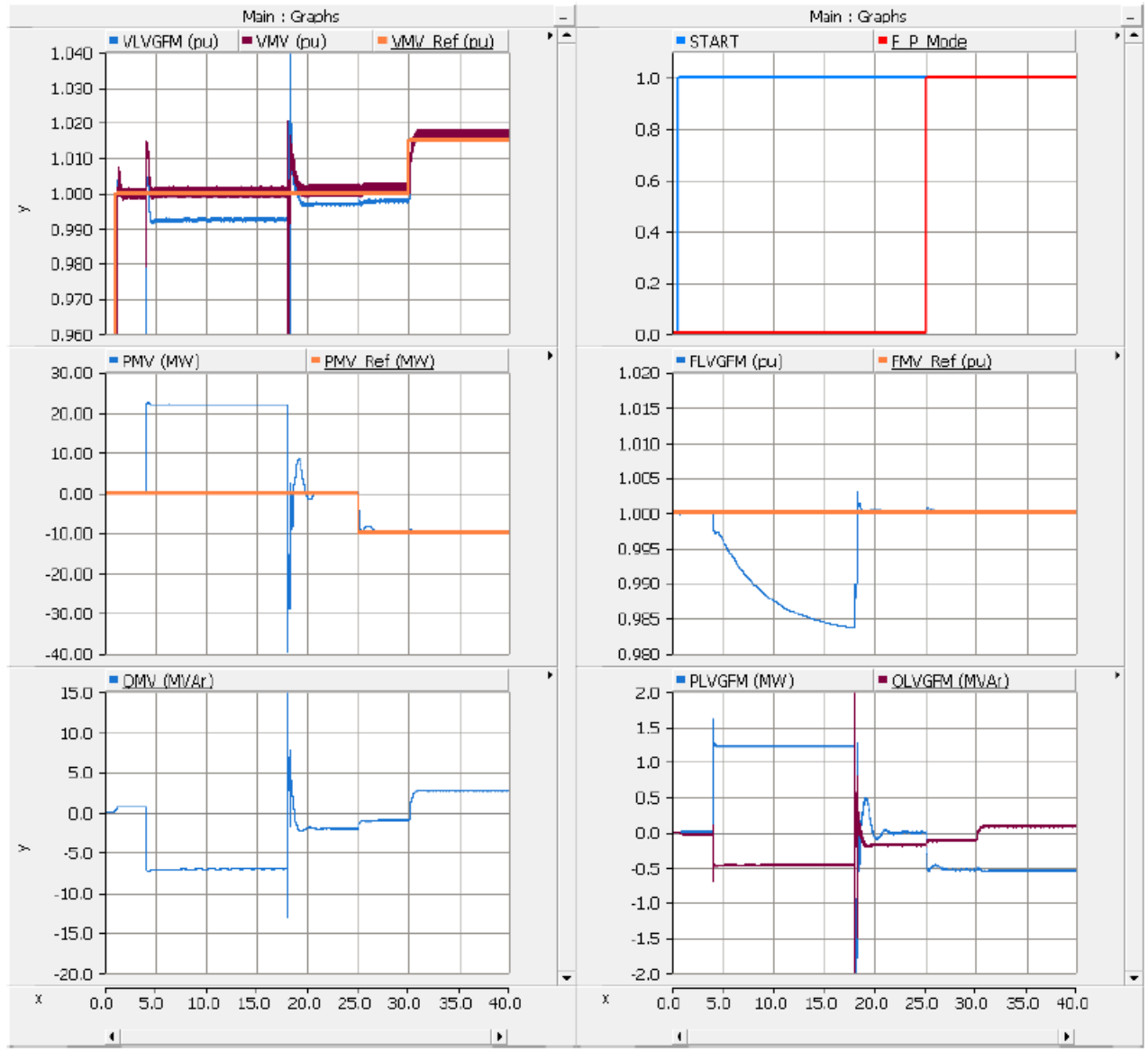


- PLVGFM – converter real power (MW per converter)
- QLVGFM – converter reactive power (MVAr per converter)
- VLVGFM – converter terminal voltage magnitude (filtered) (pu on 600V)
- FCNV – frequency of converter voltage (rad/s)

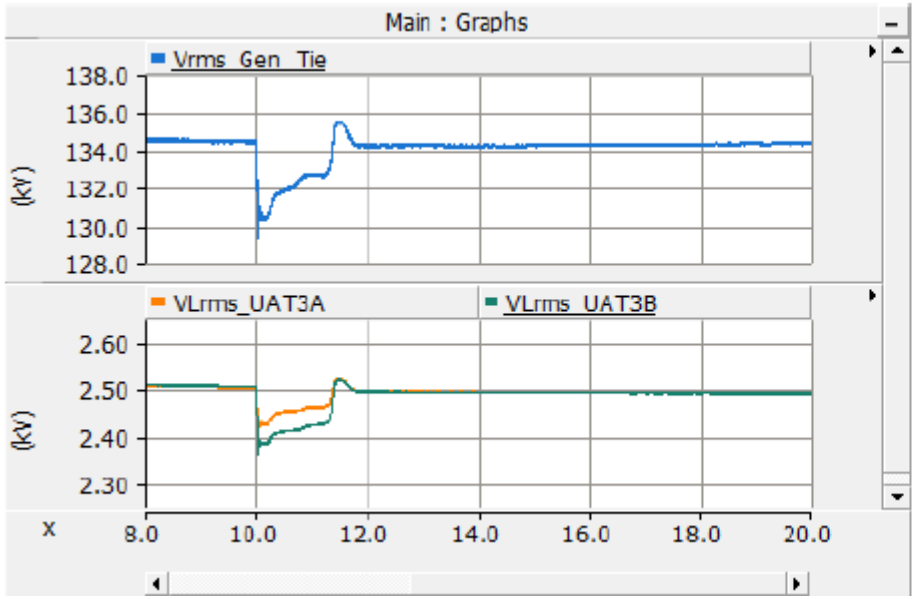
PSCAD BESS Model Testing

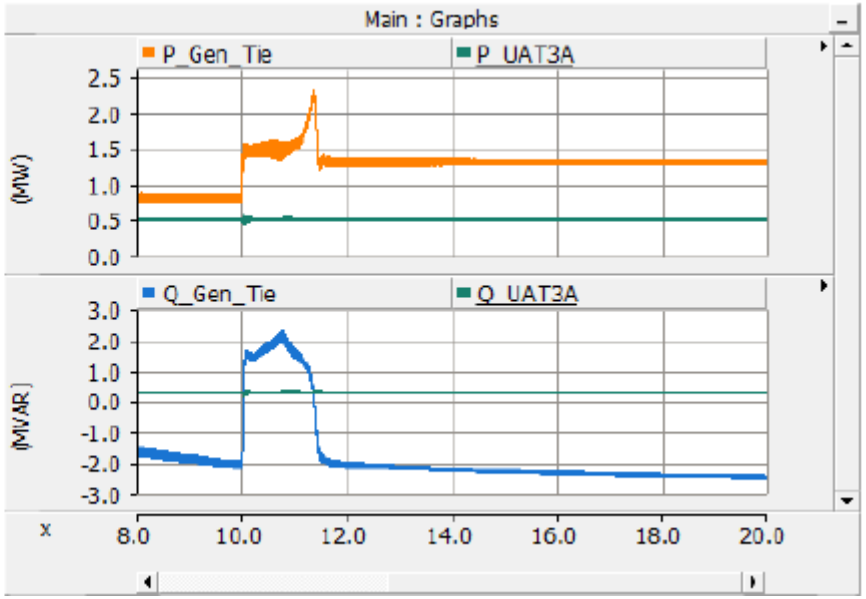


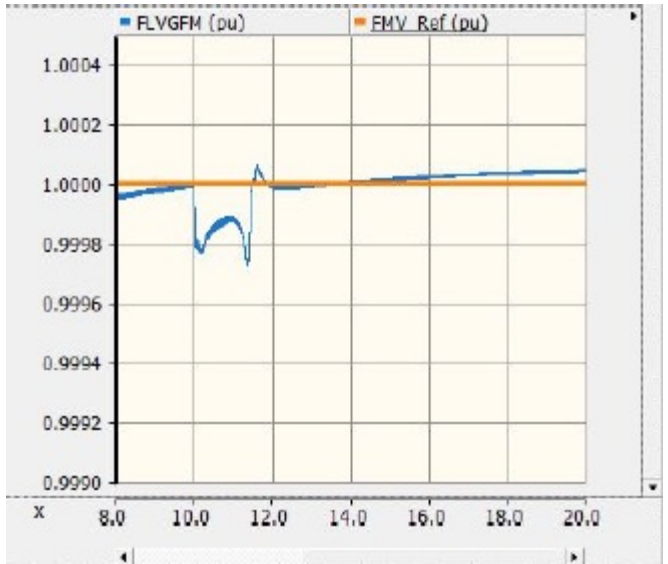
BESS Performance During Island and Grid-Connected Mode

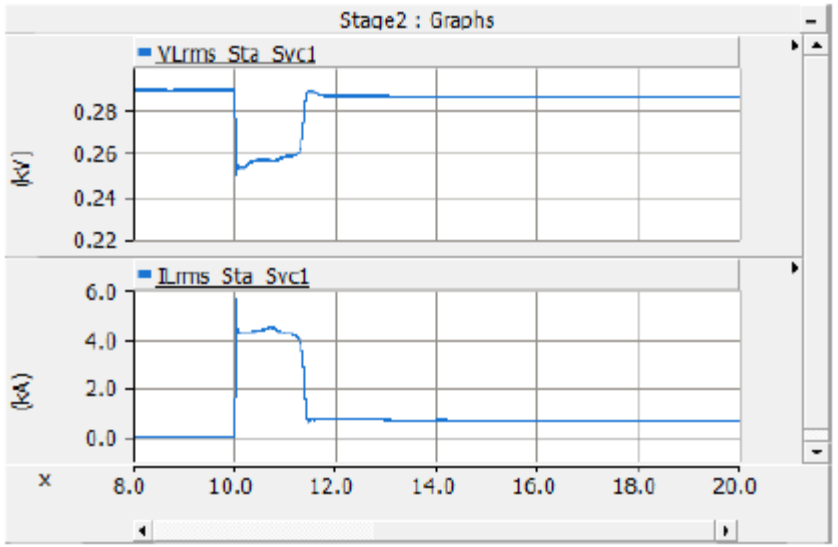


BESS Performance During Energization of the Auxiliary Motor Load at 480V









EMT Studies for System Restoration

- SCE is in the process of exploring the blackstart system restoration studies that do not include target units, only peakers,
- SCE/GE GPG HMI Viewer for the open-phase detection during the black-start studies,
- SCE/EPRI GFM BESS study.

Lessons Learned

- EMT simulation results remained the same after removing two short 230kV underground cables (~1000 feet) and short gen-tie and replacing them with an equivalent capacitor. The maximum simulation time step increased from 1.3us to 13 us.
- Increasing simulation time step, using the snap feature to simulate the model after initialization is completed and using master-slave feature in PSCAD allows engineer to make quick changes to the EMT model and explore maximum load size, frequency response, voltage dip, and system recovery time before energizing the next load.

Impact

- All phases of the blackstart system restoration were simulated successfully in PSCAD using GFM BESS instead of LM6000. Voltage and frequency were well within the system limits. There was no interaction between the GFM control and system that would result in converter tripping and failed blackstart.
- GFM BESS has a great potential to become a black-start resource.

Gaps & Challenges Observed (Not Solved Yet)

- Improve system reliability and blackstart capability by identifying new cranking paths and approaches. As the number of SCE owned and operated blackstart units is decreasing and number of restoration procedures in SCE's SOB-1A document is declining, can we further improve system's blackstart capability using GFM BESS. BESS was studied as one potential solution.
- Perform separate harmonic analysis for LCI system.