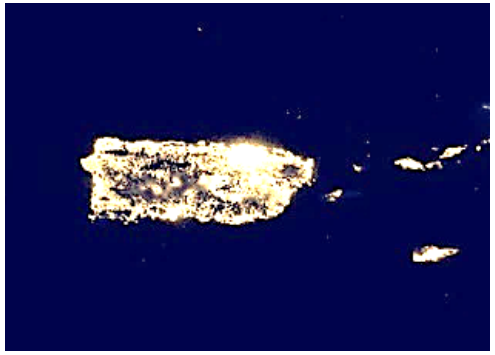
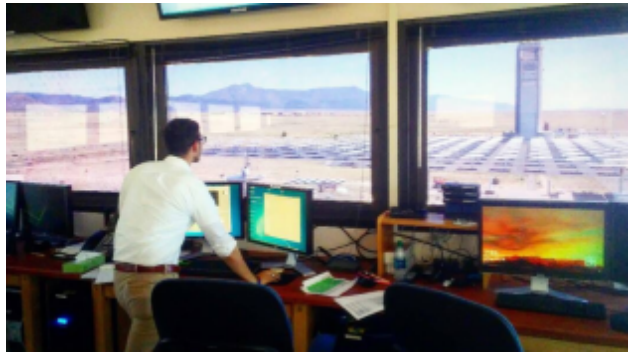
SAND2021-7426C

Exceptional service in the national interest

Sandia National Laboratories



Modeling Grid-Forming Inverter Dynamics Under Ground Fault Scenarios Using Experimental Data From Commercially Available Equipment

Presenter:
Javier Hernández-Alvídrez

Nicholas S. Gurule, Rachid Darbali-Zamora, Matthew J. Reno, and Jack D. Flicker

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

U.S. DEPARTMENT OF ENERGY

NNSA

Outline

- Introduction
- Motivation
- Theoretical Background
- Proposed Simulation Model
- Experimental Results Comparisons
- Conclusions

Introduction

- Legitimate concerns in regard to the environmental footprints caused by the massive use of fossil fuels.
- Energy generation paradigm is shifting away from conventional fossil fueled resources to a systemic and gradual increase in the use of sustainable renewable resources.
- Emerging microgrid architectures demand the use of novel and adaptable power electronic interfaces such as grid-forming inverters (GFMI).

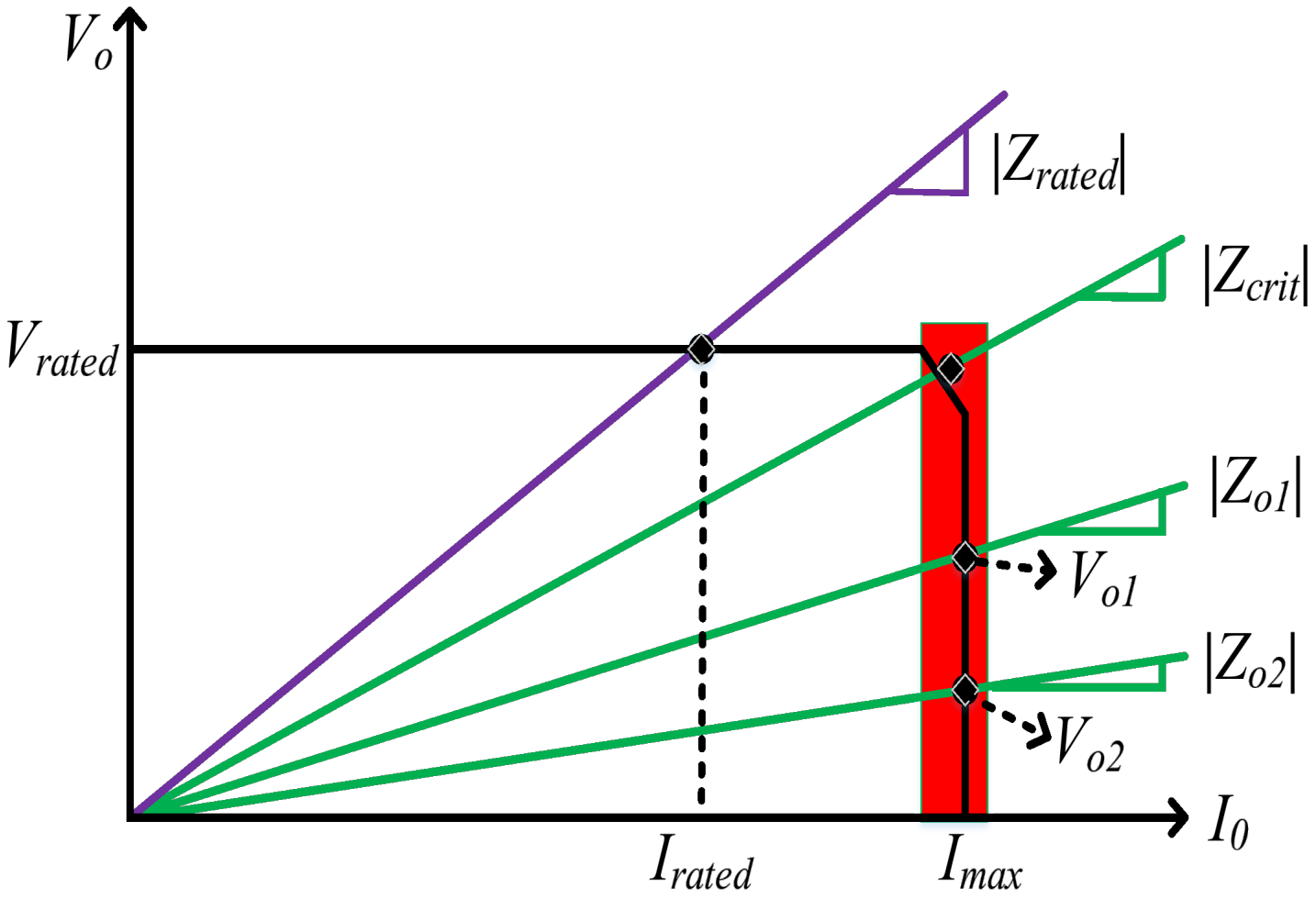
Sandia National Laboratories

Motivation

- GFMIs are gaining more popularity with respect to grid-following inverters (GFLI).
- Don’t need a dedicated synchronization mechanism, such as a PLL.
- Still a very active line of research in power conversion.
- Inherent nature of GFMI is to follow the supplied loads.
- Inverter manufacturers are reluctant to provide simulation models.
- Furthermore, modeling the current limiting dynamics of commercially available GFMIs under ground fault scenarios is limited.

Sandia National Laboratories

Theoretical Background (Protection Scheme)

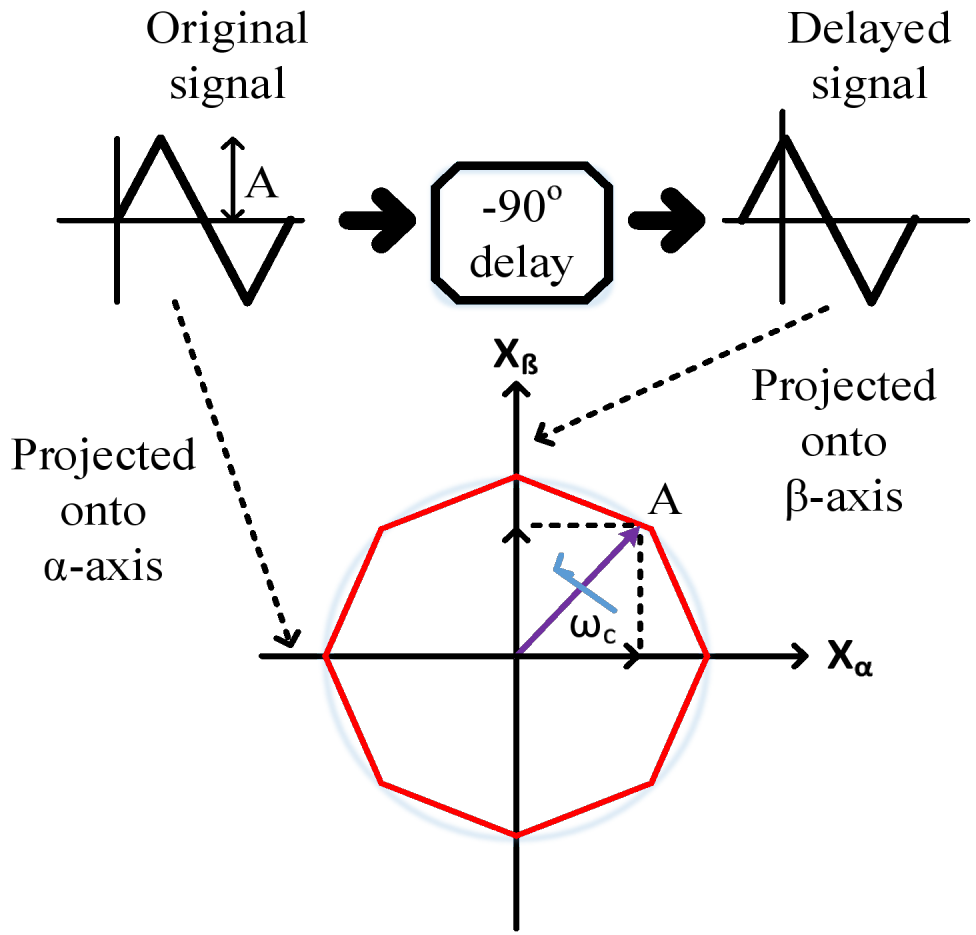


- Some commercially available GFMI tend to curtail and clip both the voltage and current amplitudes under ground related faults.
- This is similar to the Constant Current Protection Mode widely used in DC to DC converters.
- In order to adapt this protection scheme to the CERTS GFMI model, a good impedance estimation technique must be used.

Sandia National Laboratories

Theoretical Background (Impedance Estimation)

$$\begin{bmatrix} x_\alpha \\ x_\beta \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix}$$



- Impedance estimation cannot use the raw time-varying measurements due to the zero crossing nature of AC signals.
- Since the CERTS model uses the stationary αβ-frame, the transformed values of voltage and current can be directly used to estimate the impedance of the load, thus:

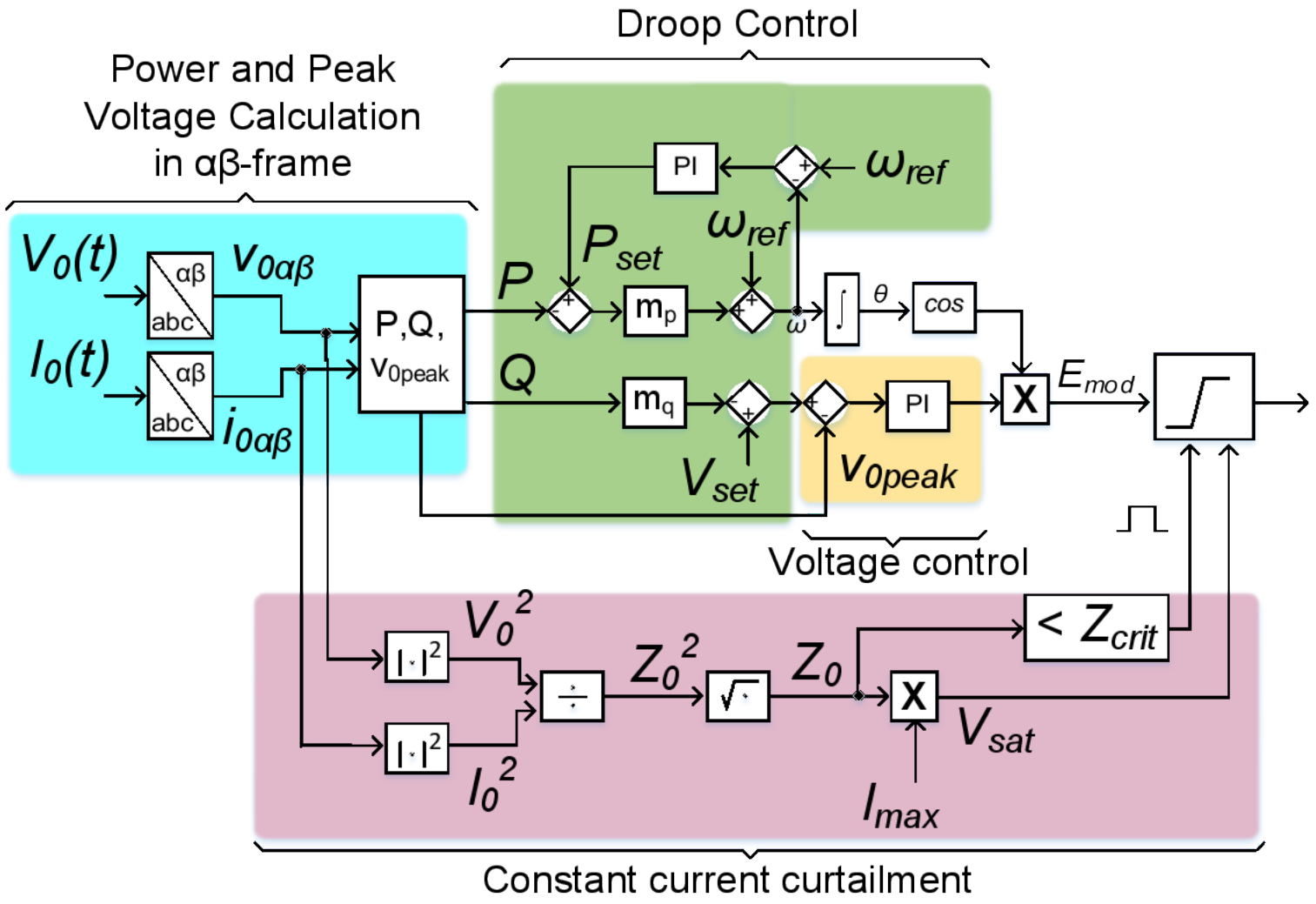
$$I_0^2 = I_{0\alpha}^2 + I_{0\beta}^2$$

$$V_0^2 = V_{0\alpha}^2 + V_{0\beta}^2$$

$$Z_O = \sqrt{\frac{V_0^2}{I_0^2}}$$

Sandia National Laboratories

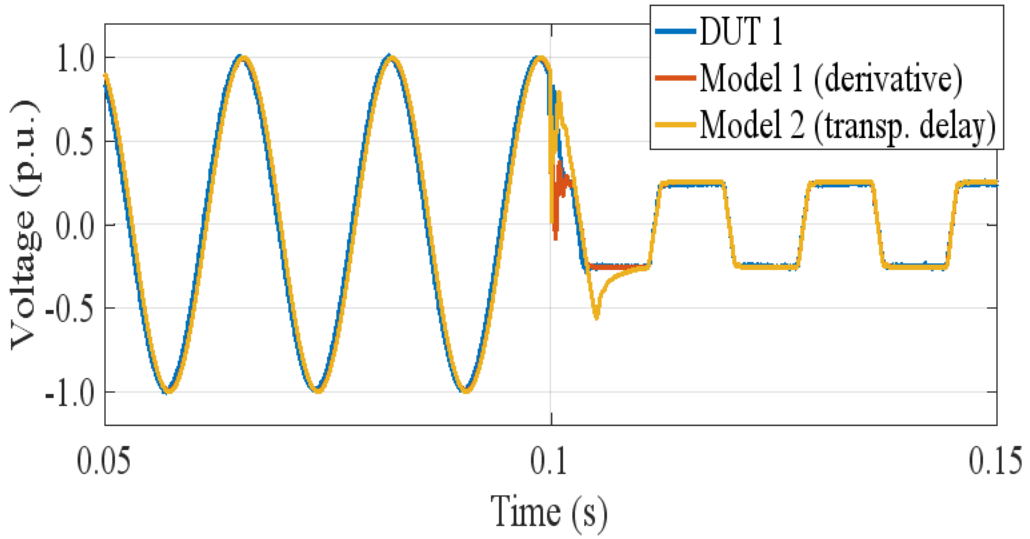
Proposed Simulation Model



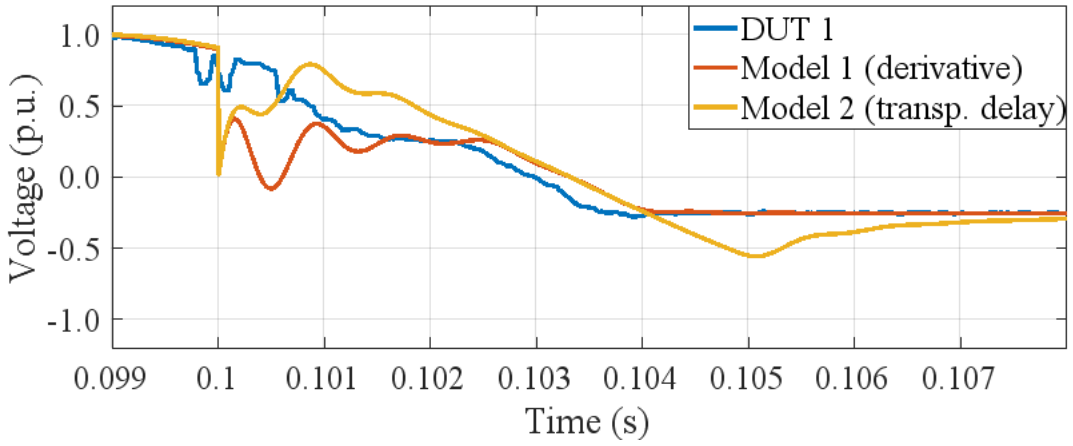
- The CERTS GFMI model was modified to include the protection scheme.
- The constant current curtailment protection scheme is depicted in the pink block at the bottom of the figure.
- The block uses the already transformed αβ values of the output voltage and current to calculate the impedance supplied by the inverter.

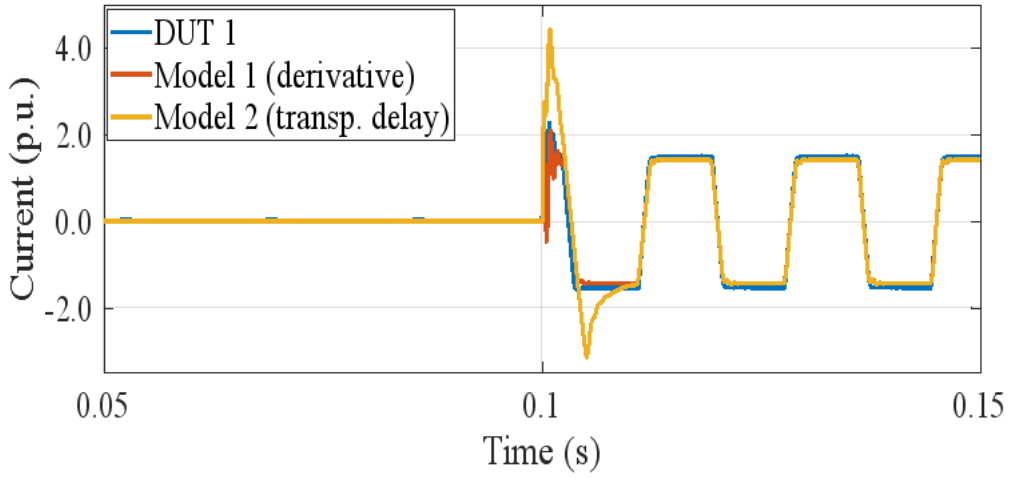
Sandia National Laboratories

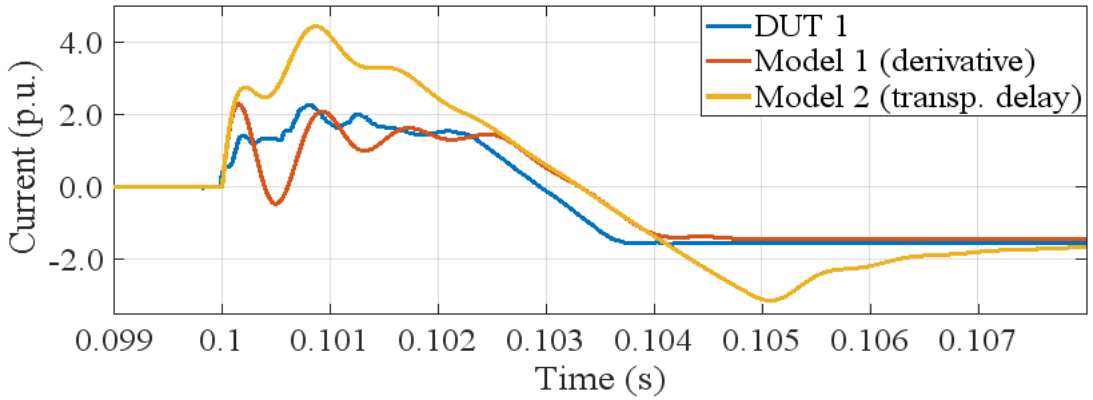
Experimental and Simulation Results comparison



Magnified portions after fault inception







Sandia National Laboratories

Conclusions

- This paper proposed and implemented a modified GFMI CERTS model that accurately models the current dynamics during faults.
- The modifications are based upon the constant current curtailment protection widely used in DC/DC converters, and make use of the original model measurements in the αβ-frame domain.
- Simulation and experimental results showed very similar transient dynamics.

Sandia National Laboratories

Thank You

Javier Hernández-Alvídrez

Senior Member of Technical Staff
Electric Power Systems Research
Sandia National Laboratories
jherna4@sandia.gov