# Industry Based Experience with EMT Modeling of Inverter Based Resources (IBR)

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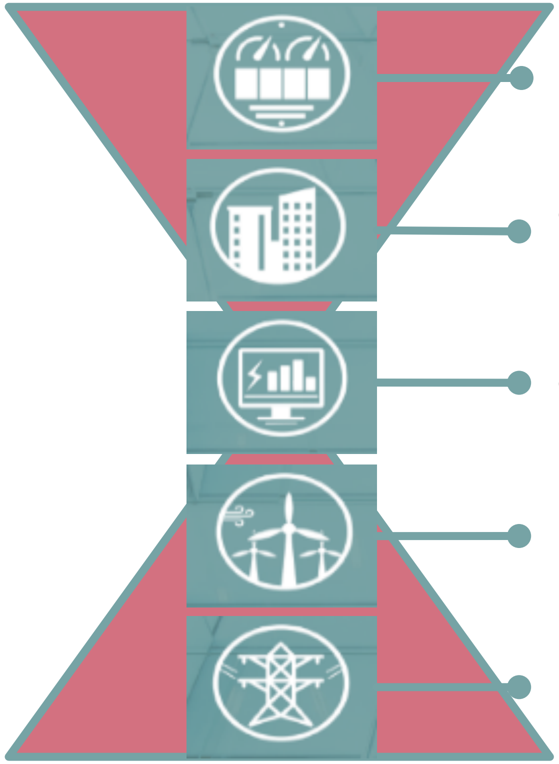
# EnerNex

## EnerNex Service Lines

**Strategic Perspective**



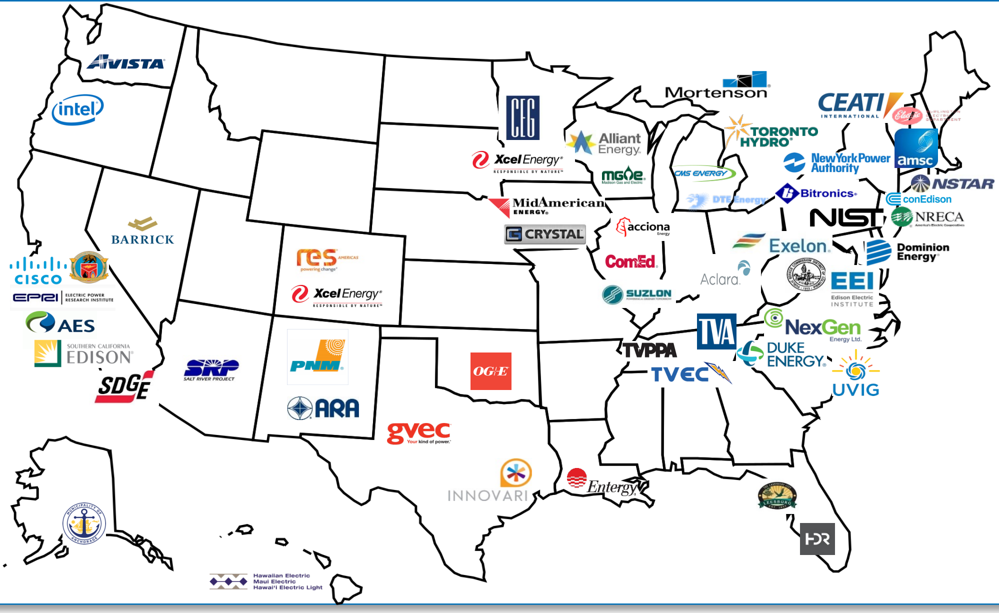
- **Electric Industry Evolution**
- **Grid Modernization**
- **Grid Technology Consulting**
- **Renewable & Distributed Resource Integration & Interconnection**
- **Electric Energy System Engineering & Analysis**

**Tactical Perspective**

## Sample of EnerNex's Capabilities

- **Strategic Planning**, road maps, program development, use-case and specifications, business case support
- **DER & Intermittent Resource** integration, grid modernization, technology plans & support
- **Demand Response** business planning, technical requirements
- **Storage & Microgrid** technical guidance covering initial feasibility through commissioning
- **Solar & Wind** modeling, integration & interconnection studies & recommendations
- **Cybersecurity** evaluation of strategies, risks, requirements, & mitigation measures

## Key EnerNex US clients

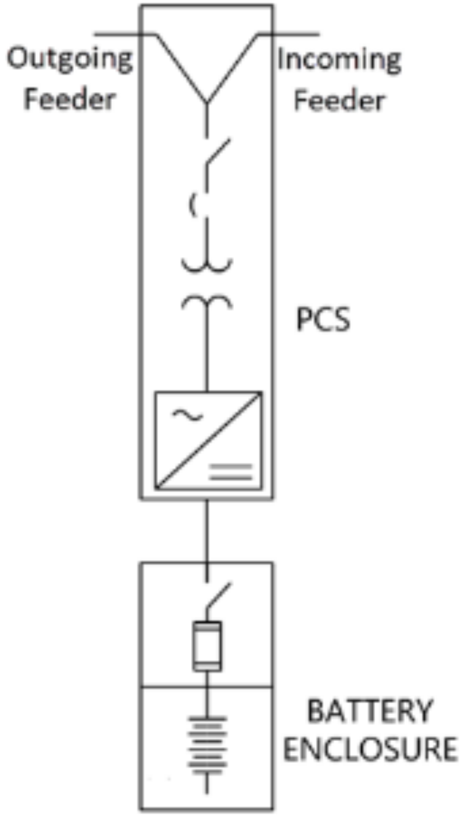


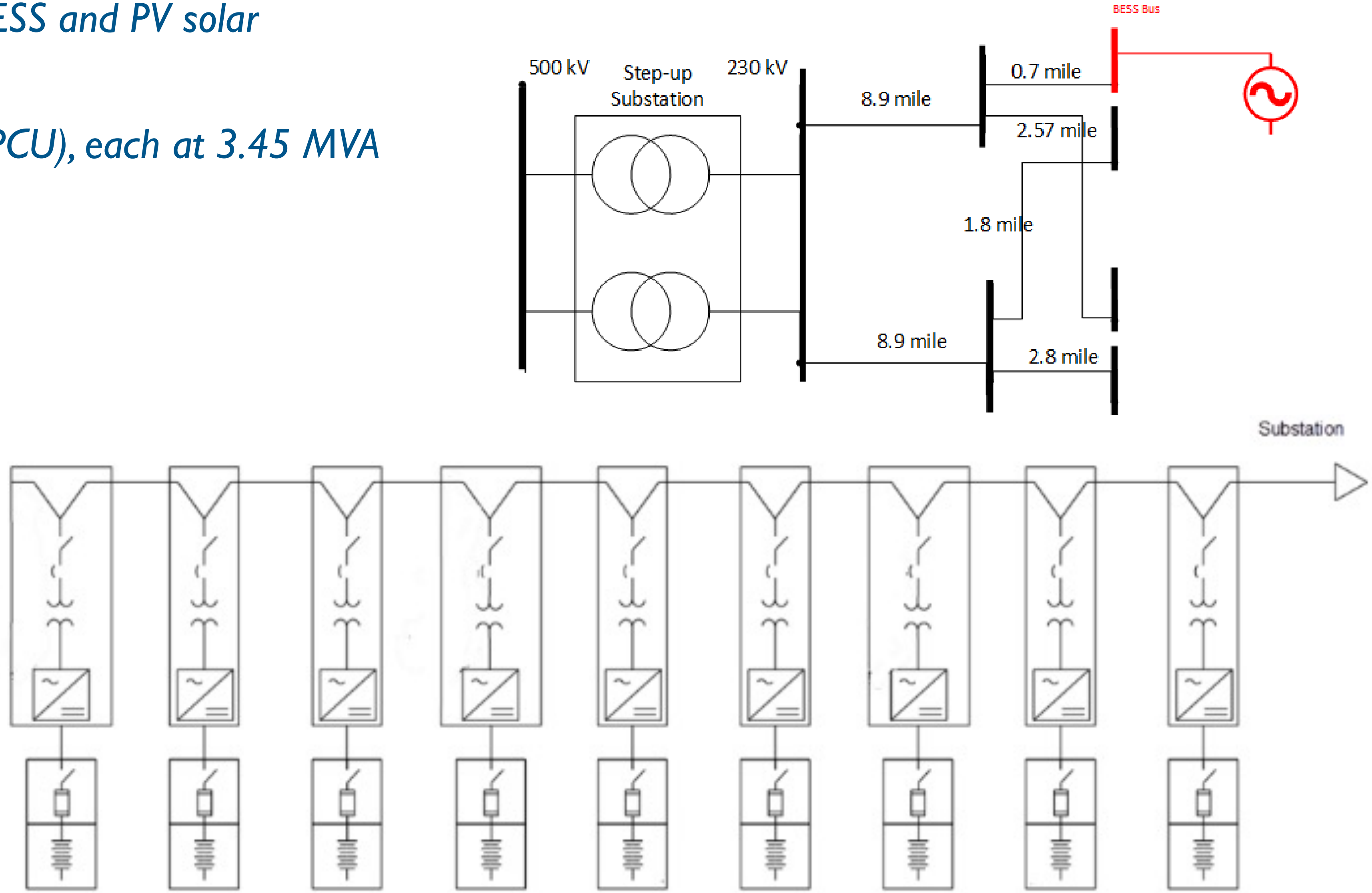
# EnerNex Experience

- *Transmission System/Utility Studies*
- *Wind Power Plant Studies (22,000 MW)*
- *Solar Power Plant Studies (9,000 MW)*
- *BESS (Battery Energy Storage System) Plant Studies*

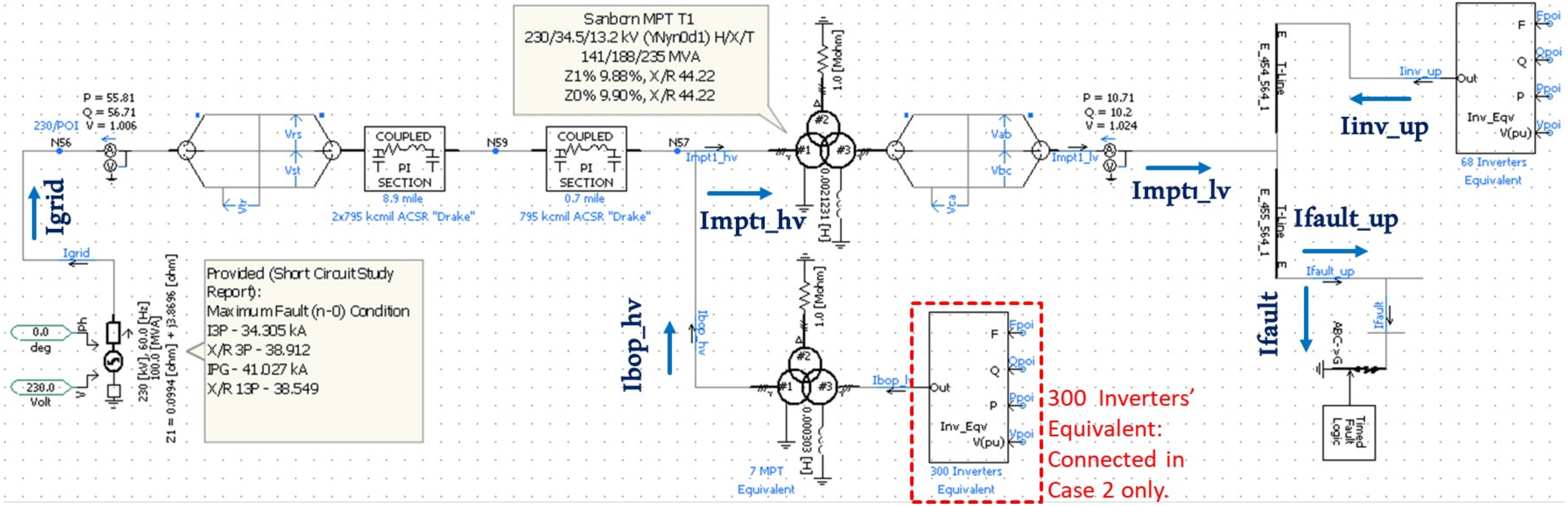
# BESS Project Description

- *Large 204 MW Plant with BESS and PV solar connected at 230 kV*
- *68 Power Conversion Units (PCU), each at 3.45 MVA (0.633/34.5 kV)*



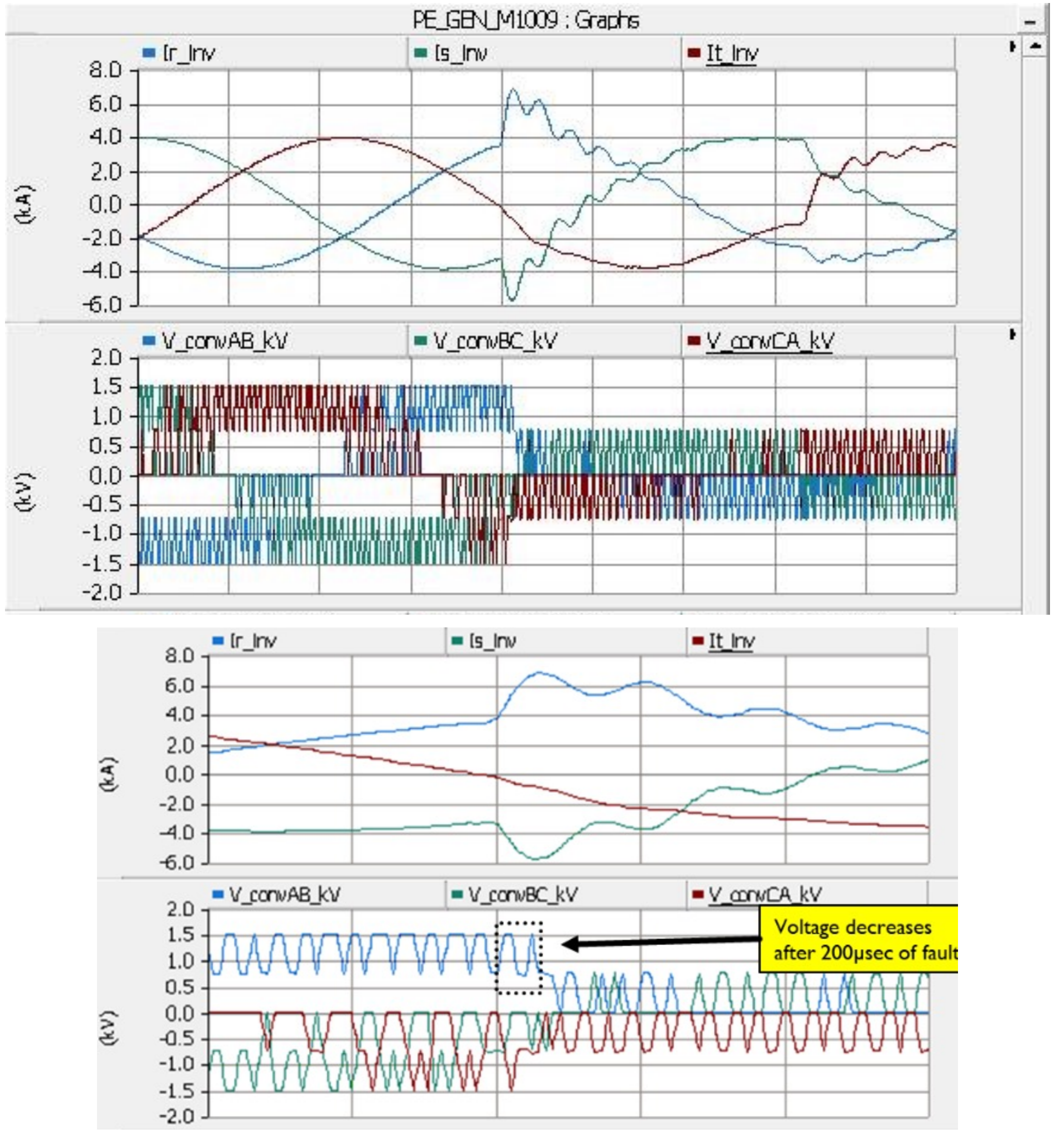



# PSCAD Model File

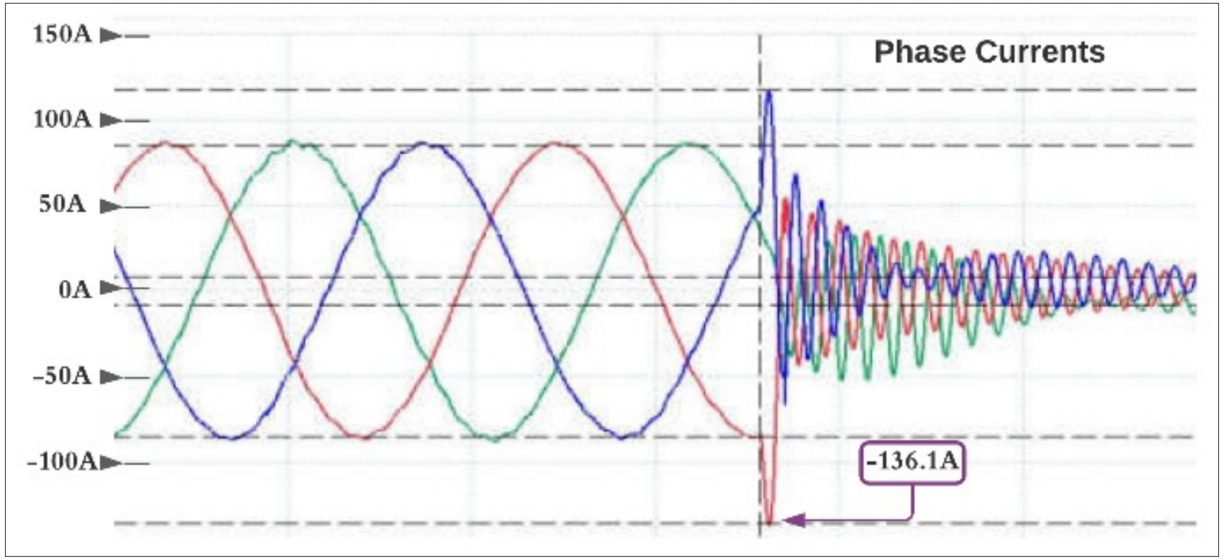


# Inverter Short Circuit Response

*The model file of the inverter has a current limiting response within 200 usec after the onset of the short circuit fault. The laboratory tests available confirmed a similar response.*

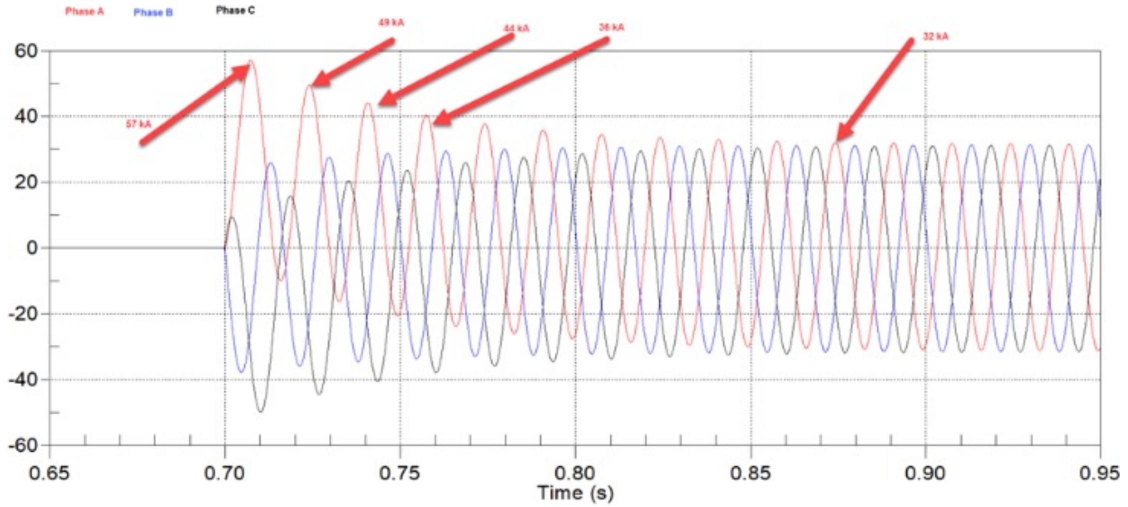


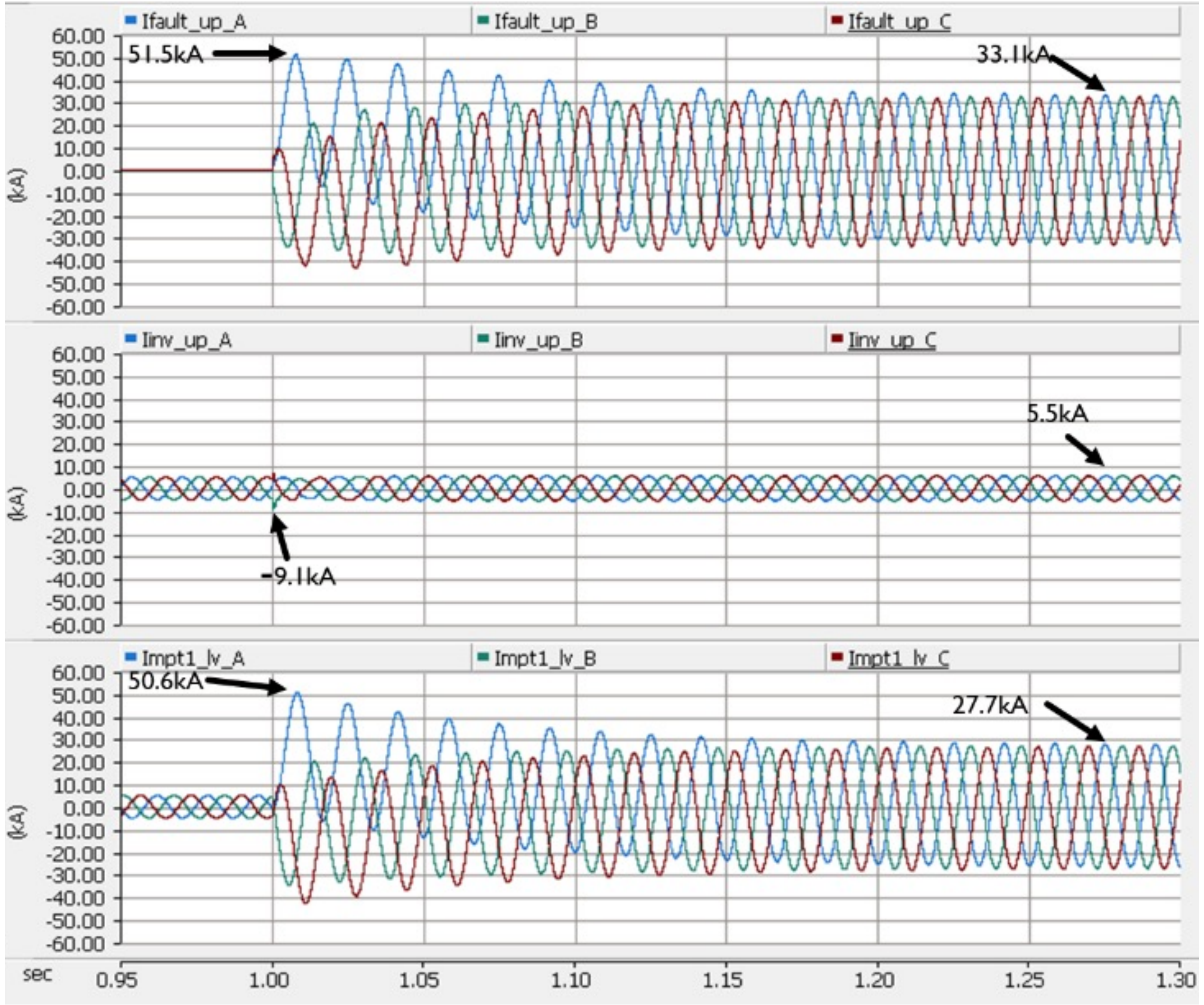

*PSCAD Model File Response (Single Phase Fault)*




*Laboratory Test Result (3 Phase Fault)*

| Model | Asymmetrical Peak kA |
|---|---|
| Phasor-domain | 63.2 |
| Simplified time-domain | 57 |
| Detailed time-domain | 53 |



# Results from Calculations and Simulations

*The equipment was tested to confirm a rating for an asymmetrical peak fault current of 63.6 kA*

- *The traditional phasor domain calculations result in an asymmetrical peak fault current of 63.2 kA*
- *EMT results (inverter as simple sources) result in an asymmetrical peak fault current of 57 kA*
- *Detailed EMT simulations (inverter switching models) result in an asymmetrical peak fault current of 53 kA*

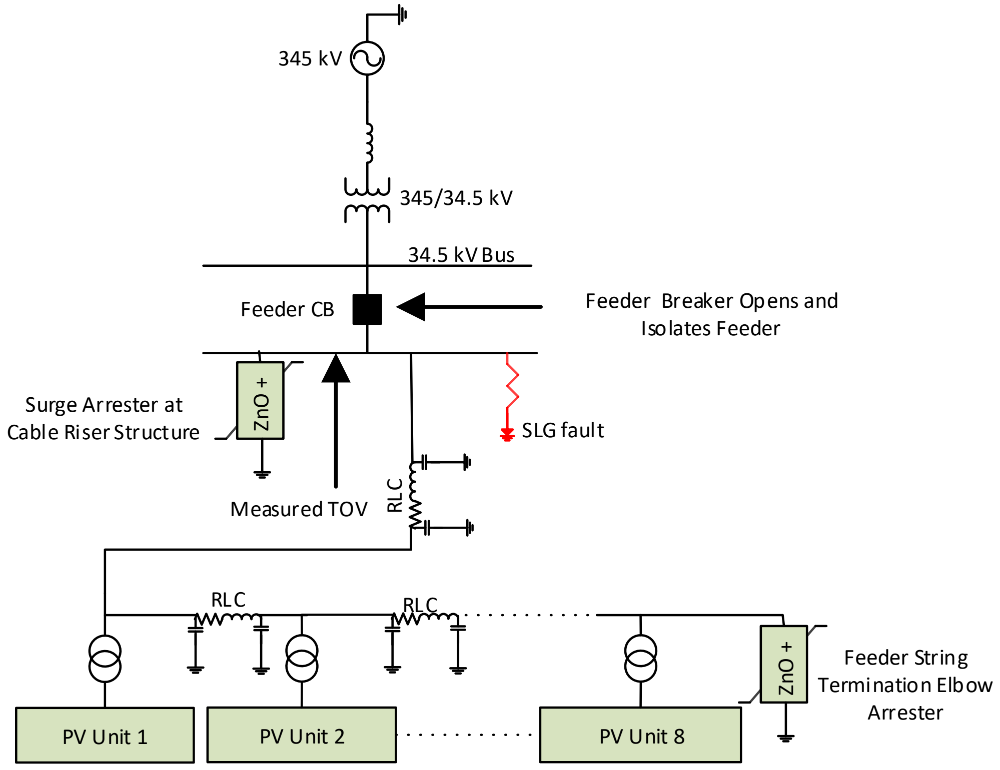
Commercial fault calculation software are based on the methodology of IEEE ANSI C37.010-1979 was included in the IEEE "Violet Book."

"IEEE Application Guide for AC High-Voltage Circuit Breakers > 1000 Vac Rated on a Symmetrical Current Basis," IEEE Std C37.010-2016

The related content from the IEEE Violet book is now "IEEE Recommended Practice for Conducting Short-Circuit Studies and Analysis of Industrial and Commercial Power Systems," IEEE Std 3002.3-2018.

# TOV Concerns in Solar Plants

- *Collector systems of solar plants are grounded by the main power transformer at the substation.*
- *Single Line to Ground (SLG) fault on collector system.*
- *Collector system circuit breaker opens and isolates the collector, while PV inverters continue to operate.*
- *This condition creates a system without a ground source, but with one phase still connected to ground.*
- *The un-faulted phase voltages will increase significantly, typically to 3 per-unit of the pre-fault voltage if the feeder does not include any overvoltage mitigation.*




**Simplified Diagram of Solar Plant Feeder for TOV Analysis**

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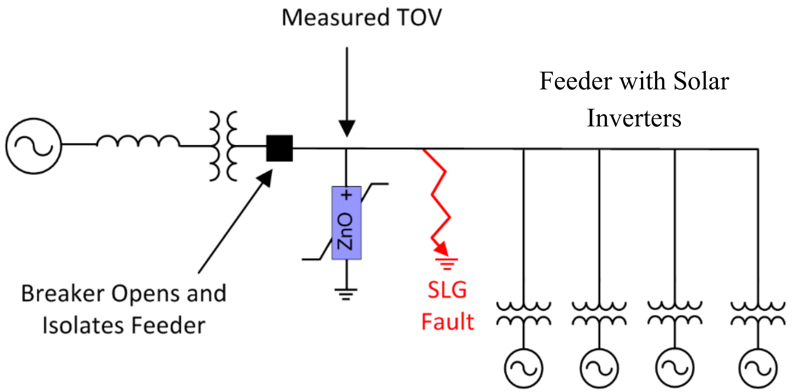
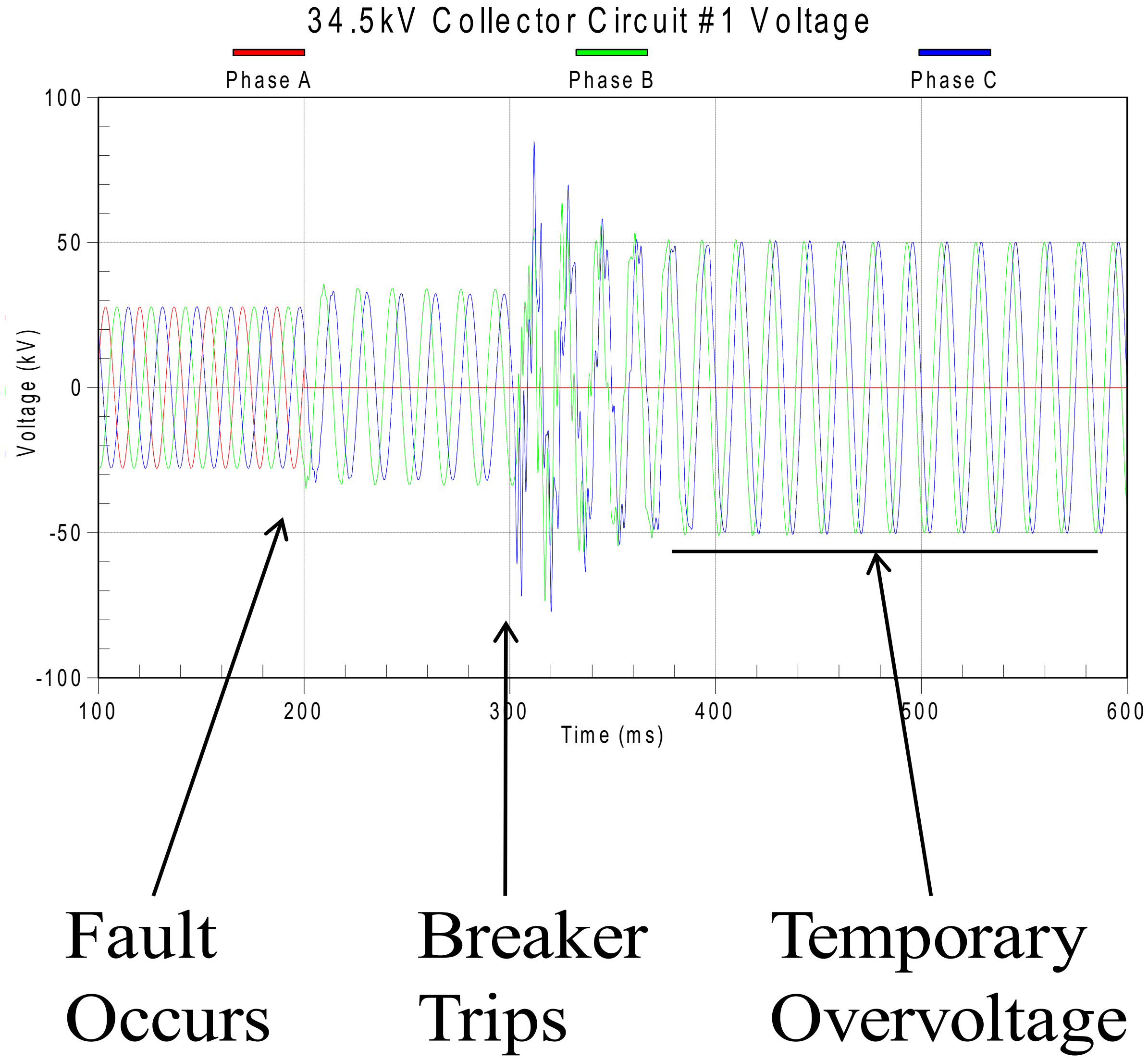
# TOV Event Sequence



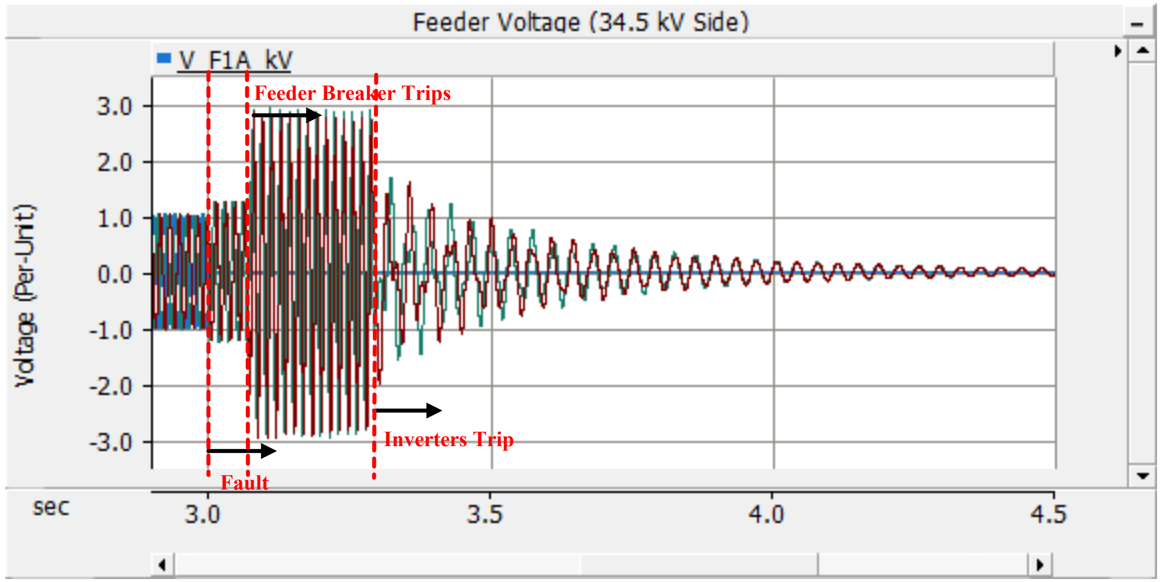

1. *Single line to ground fault occurs*
2. *Feeder circuit breaker trips, feeder is islanded*
3. *Temporary overvoltage until inverters trip*



# TOV Study Results of a PV Inverter (No Mitigation)

**Inverter default overvoltage trip settings: 1.3 pu and 0.2333 sec (14 cycles)**.

- **Case 1**: Single-Line-To-Ground Fault, No Surge Arrester




- Single-line-to-ground fault at 3 seconds,
- The feeder circuit breaker opening at 3.0667 seconds,
- All of the PV Inverters tripping at 3.300 seconds.

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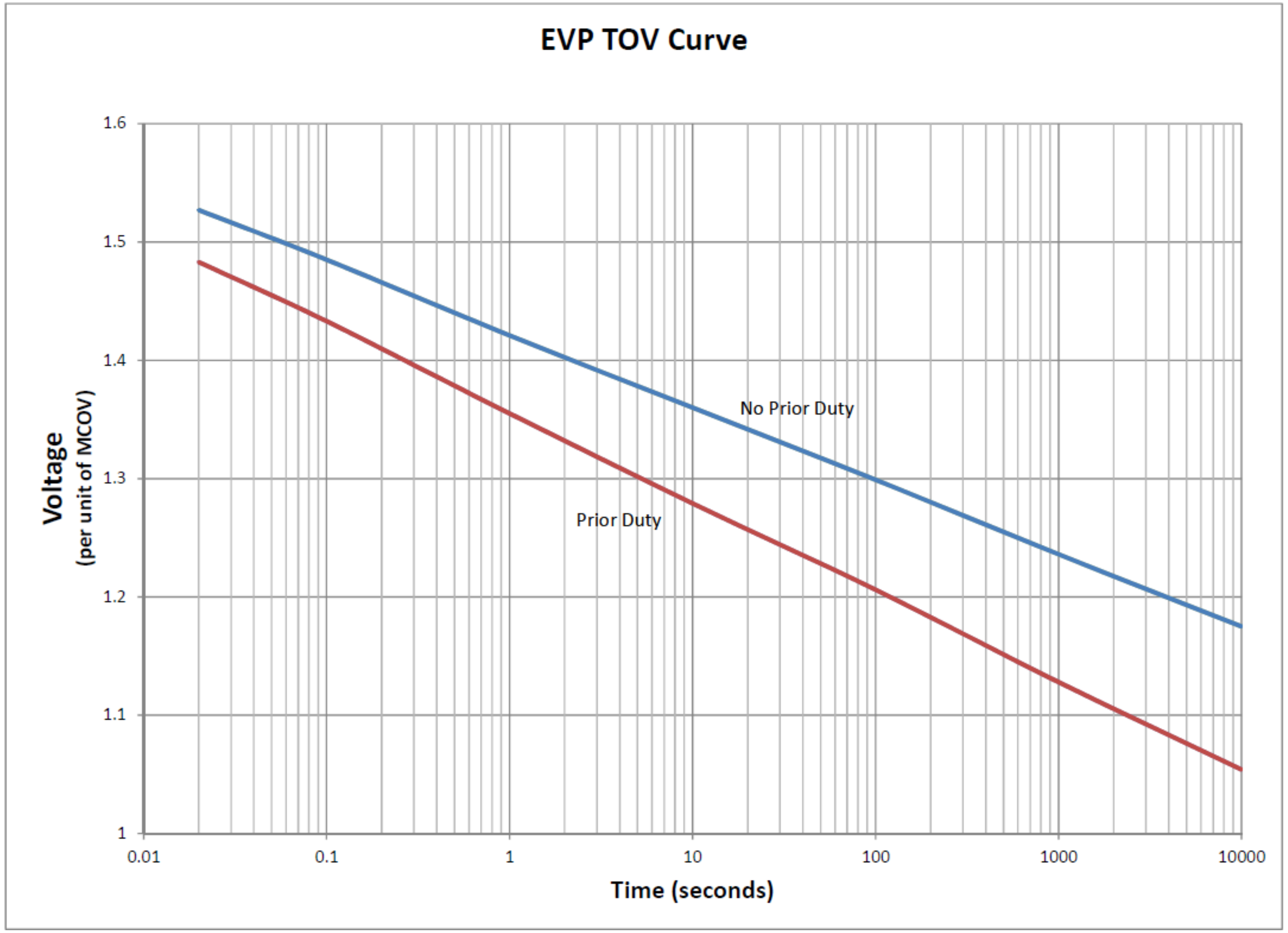
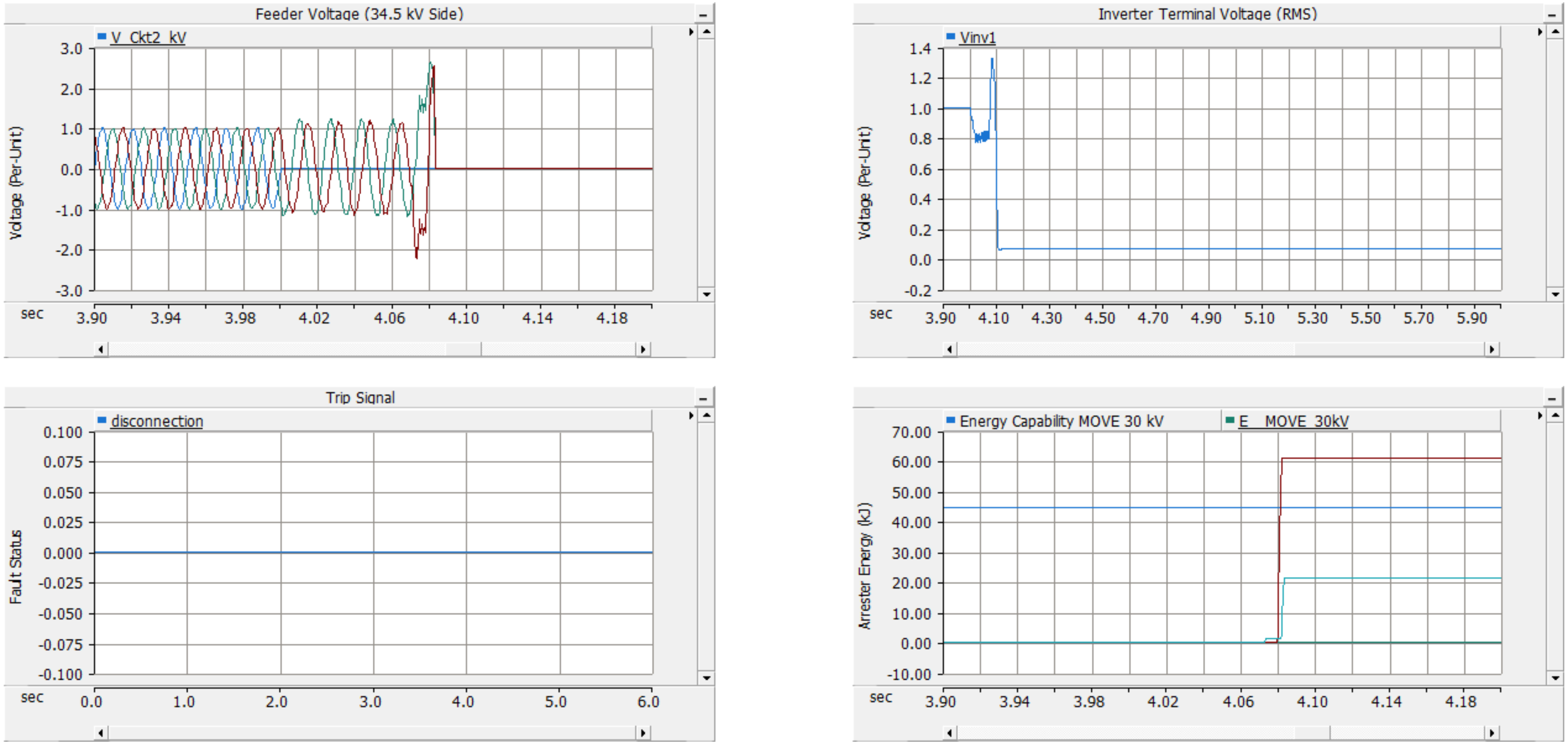
# Surge Arrester Temporary Overvoltage / Transient Overvoltage

- *During faults and islanding conditions.*
- *Concern is when the voltage exceeds the Maximum Continuous Operating Voltage (MCOV) of surge arresters*
- *Evaluated against the arrester TOV capability*



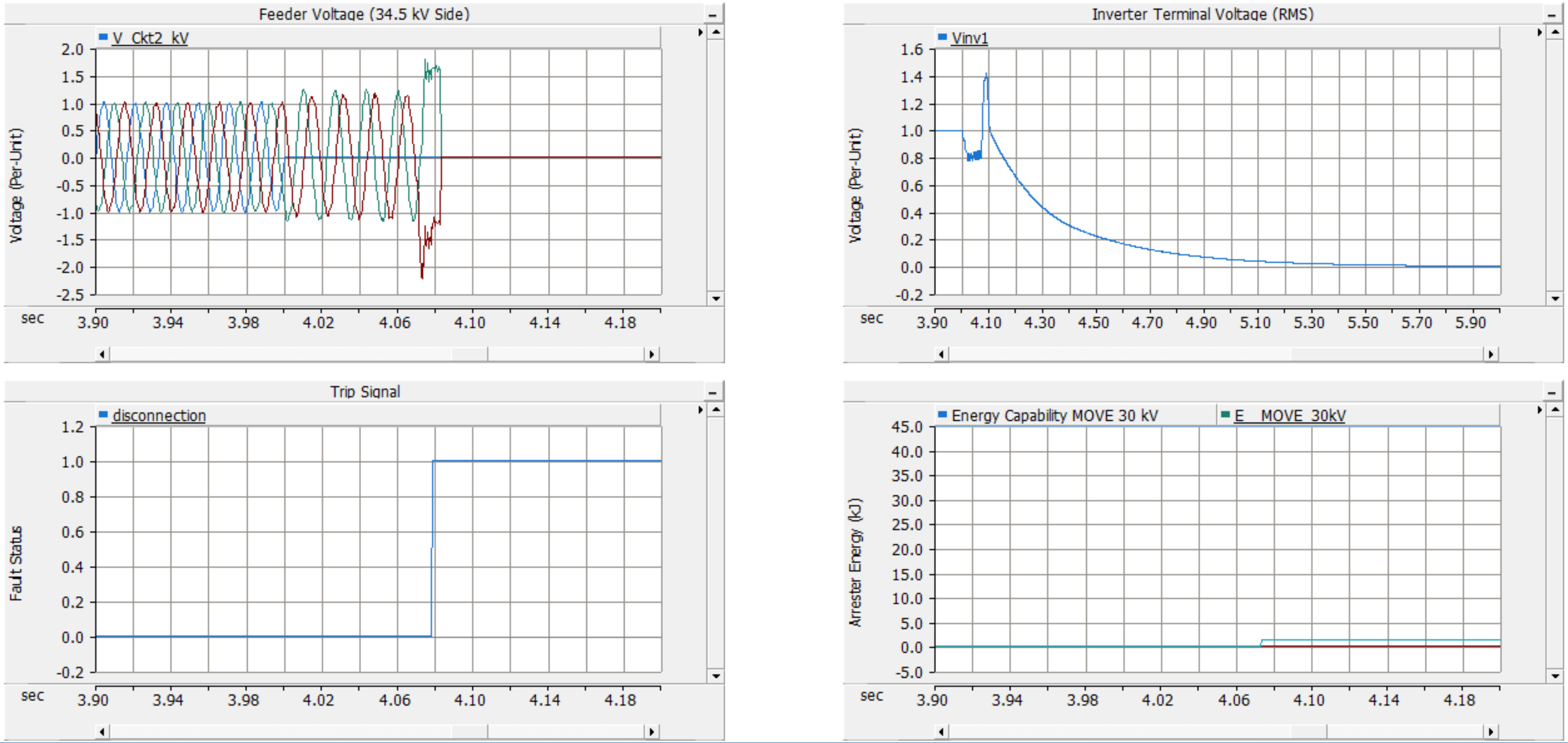
# Grounding Breaker without SPOV

- ***Case 1.2**: Single-Line-To-Ground Fault, with Elbow Surge Arrester, **Feeder EMA grounding breaker, inverter** default **overvoltage trip settings (1.3 pu and 60 ms), and high phase instantaneous protection (1.4 pu and 6 ms) disabled***



# TOV with SPOV Enabled

- ***Case 2.2****: Single-Line-To-Ground Fault, with Elbow Surge Arrester,* ***Feeder EMA grounding breaker, inverter*** *default* ***overvoltage trip settings (1.3 pu and 60 ms), and high phase instantaneous protection (1.4 pu and 6 ms)*** *enabled*

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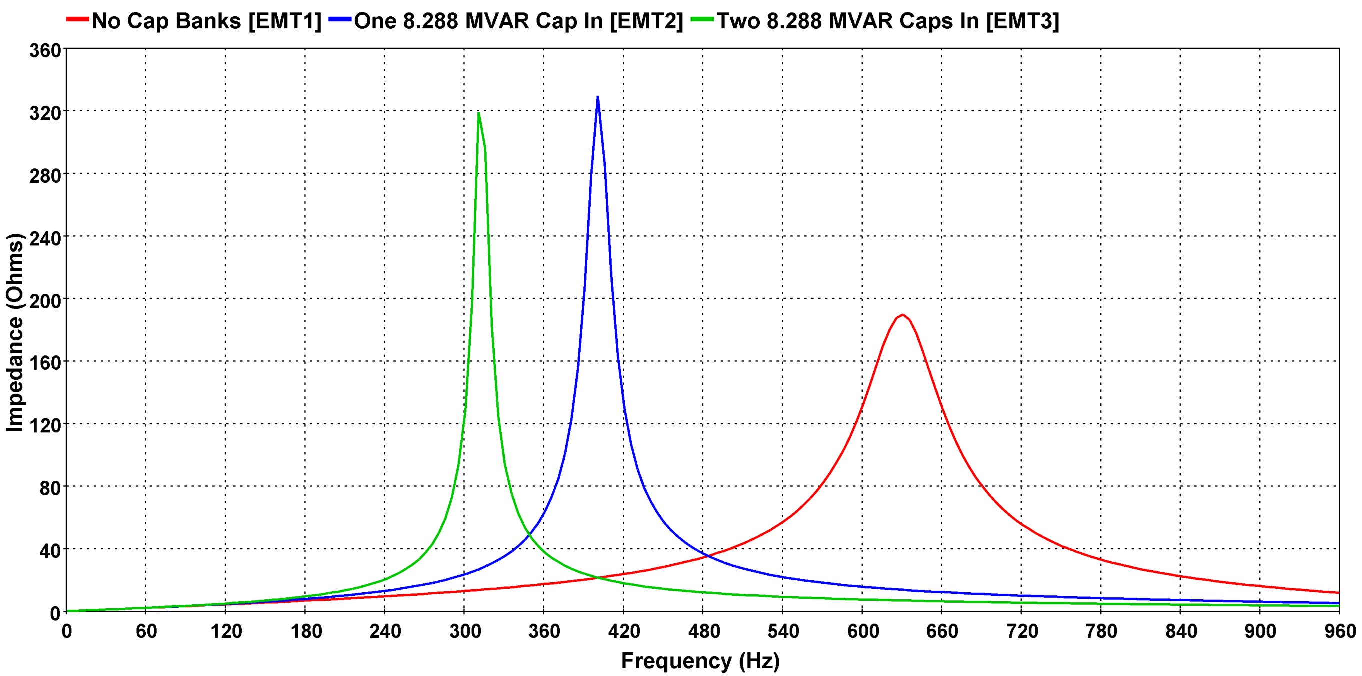
# PV Plant Resonant Harmonic Frequency Scan Analysis




| Case | System Components in service | | | | Capacitor Banks (MVAR) | Frequency Peak 1, Peak 2 (Hz) | Harmonic number Peak 1, Peak 2 |
|---|---|---|---|---|---|---|---|
| | F11 | F12 | F21 | F22 | | | |
| **Base case** | X.S | X.S | X.S | X.S | ---- | 631 | 10.51 |
| **Case 1** | X.S | X.S | X.S | X.S | One 8.288 | 401 | 6.68 |
| **Case 2** | X.S | X.S | X.S | X.S | Two 8.288 | 311 | 5.18 |

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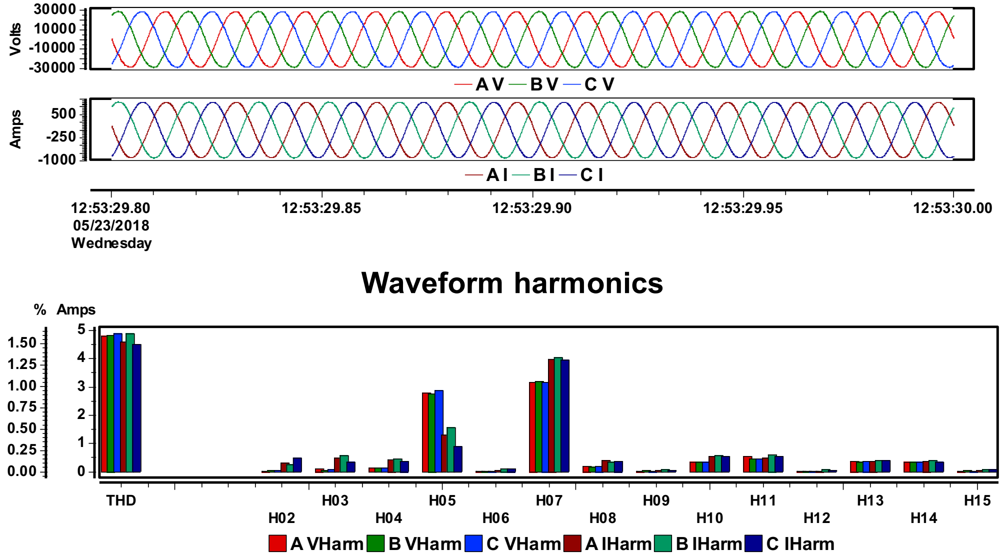
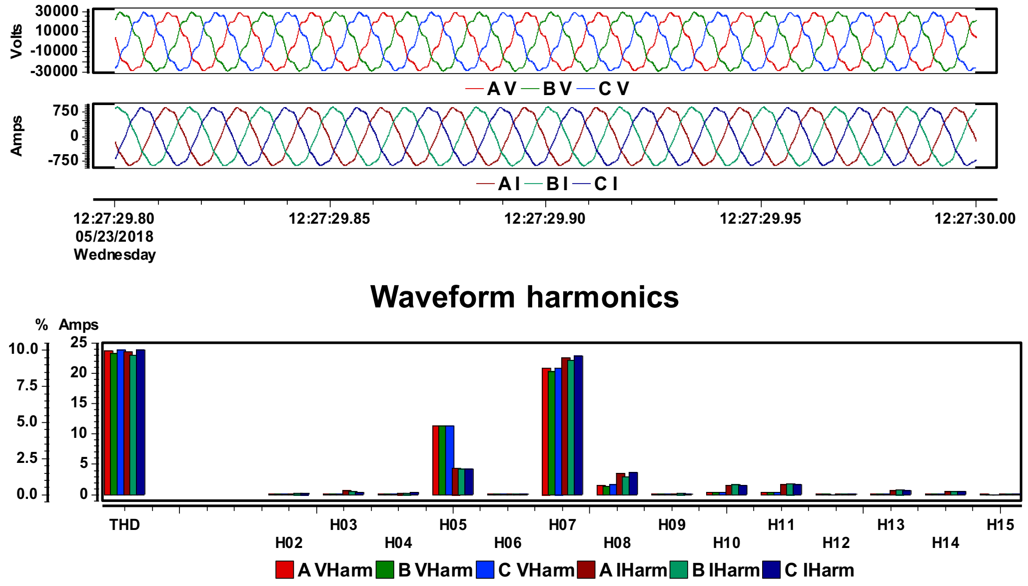
# Harmonics Measurements from PV Solar Plant (Inverters ON)

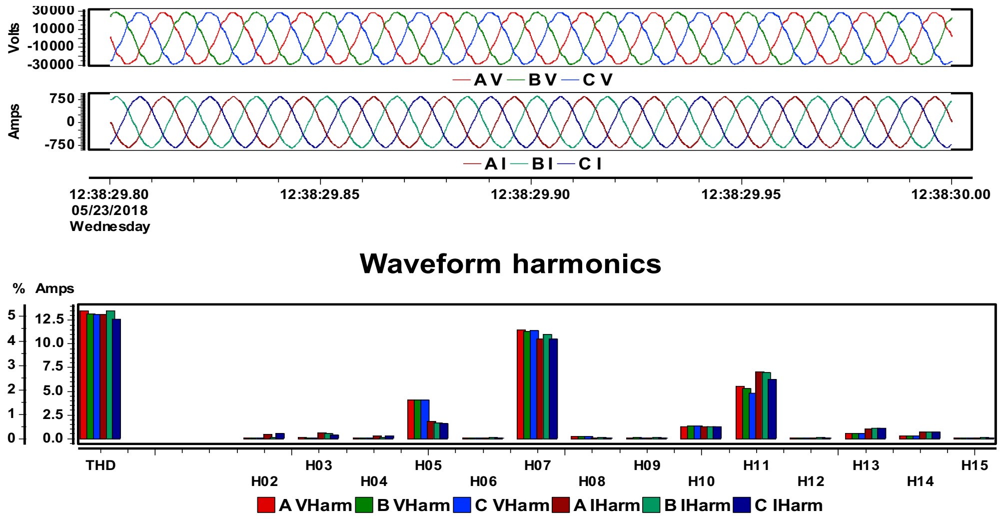
## Zero Capacitor Banks




## Two Capacitor Banks




## One Capacitor Bank




The site measurements with the inverters ON do not reflect the system resonance conditions.

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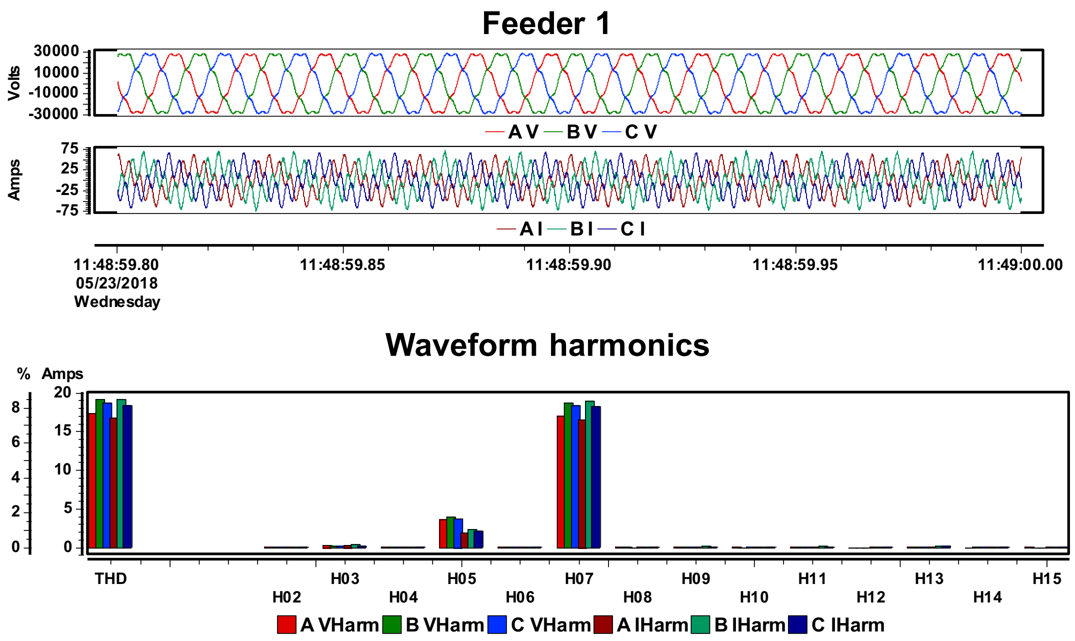
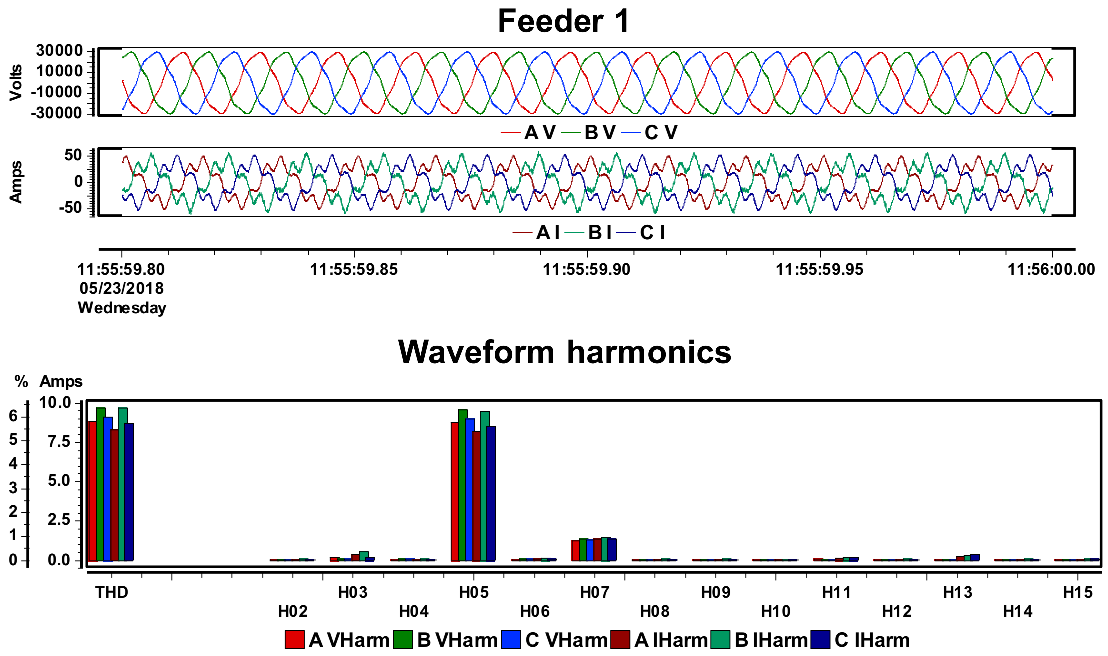
# Harmonics Measurements from Staged Testing (Inverters OFF)

## One Capacitor Bank



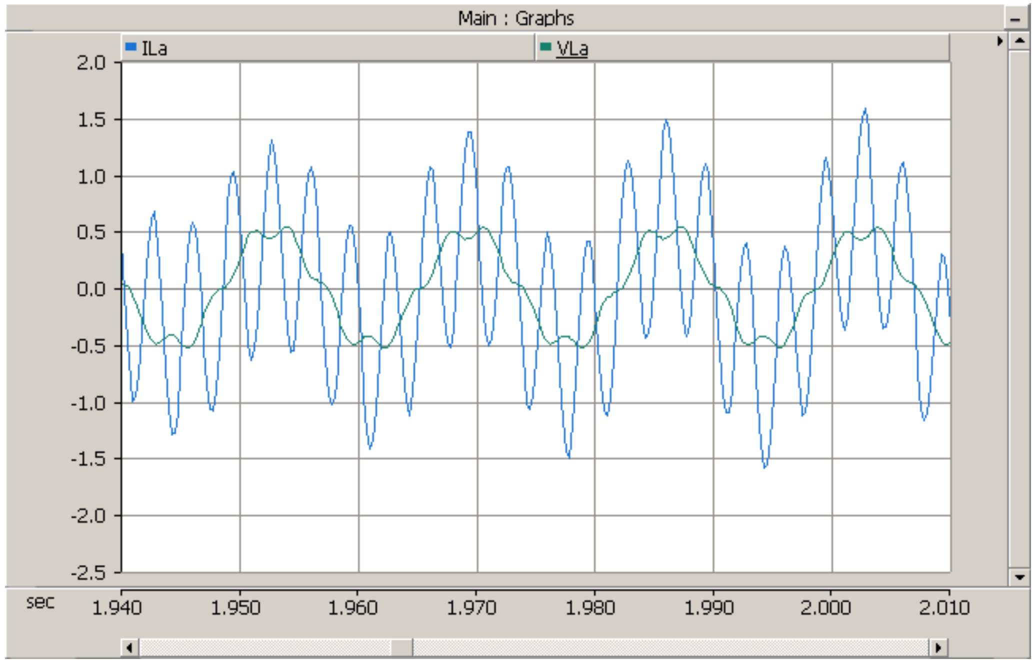

## Two Capacitor Banks



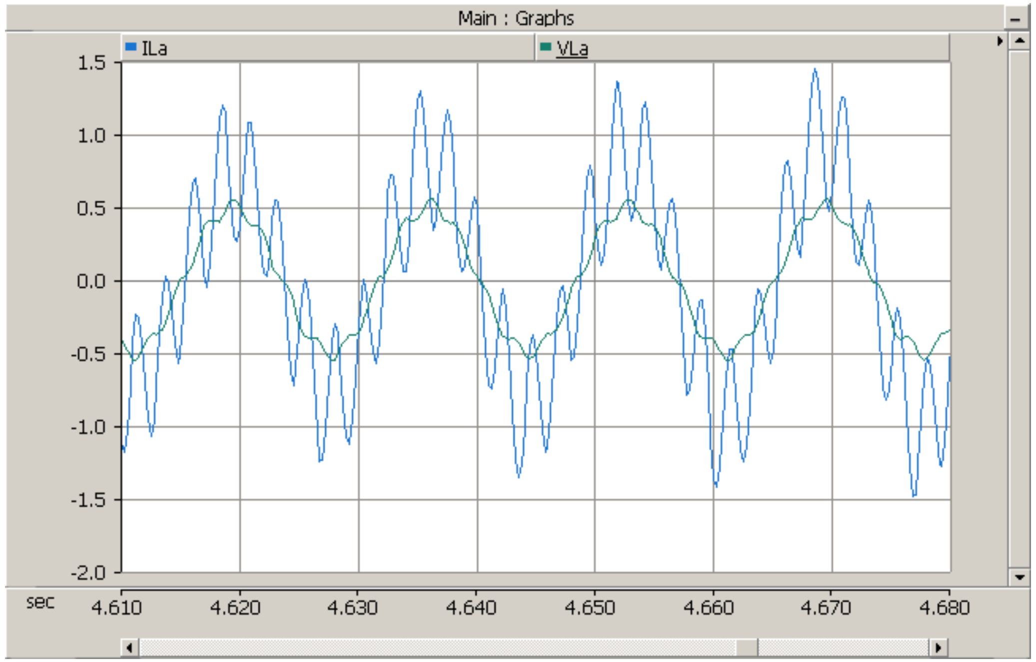

Staged testing showed expected results without the inverters.

# PSCAD Simulations

- *One Capacitor Bank, Inverters ON*




- *Two Capacitor Banks, Inverters ON*




The PSCAD simulations revealed flawed response from the active harmonic cancellation being produced by the inverters.

# Lessons Learned Using EMT Models in IBR Plant Design Studies

- *Fault current analysis with traditional calculation tools are too conservative, resulting in over design. EMT simulations show that fault current contributions, particularly the asymmetrical component, are much lower.*
- *Temporary overvoltage studies with traditional generation models are too optimistic. EMT simulations show that islanded conditions can result in much higher overvoltage and catastrophic arrester energy duty.*
- *Harmonics studies with conventional frequency/phase domain models will not always match field conditions. EMT simulations sometimes can show instability or other active inverter control characteristics that can aggravate harmonics conditions.*

*Inverter based renewable (IBR) plant design benefits greatly from high fidelity, accurate EMT models of wind turbines and inverters. IEEE P2800.2 "Recommended Practice for Test and Verification Procedures for Inverter-based Resources (IBRs) Interconnecting with Bulk Power Systems" is being drafted which will certainly contain many recommendations for the validation, verification, and use of EMT models.*

# Plant Aggregate Model Development and Deficiency Checks

## *Model Development*

- Power flow data
  - Gen-tie
  - MPT and inverter transformers
  - Collector system
- PPC and inverter control functions
  - Voltage control
  - Frequency response
  - Fault ride-through
- Operating scenarios (for hybrid plants)
  - PV only
  - BESS only
  - PV and BESS

## *Model Testing*

- Model accuracy, usability, and efficiency tests
- Performance tests
  - Flatrun
    - Initialization time
    - POI voltage, active and reactive power
  - PPC control functionalities
    - Voltage control
    - Frequency response
  - Fault ride-through
    - Tripping, momentary cessation, oscillations, recovery to pre-fault conditions.

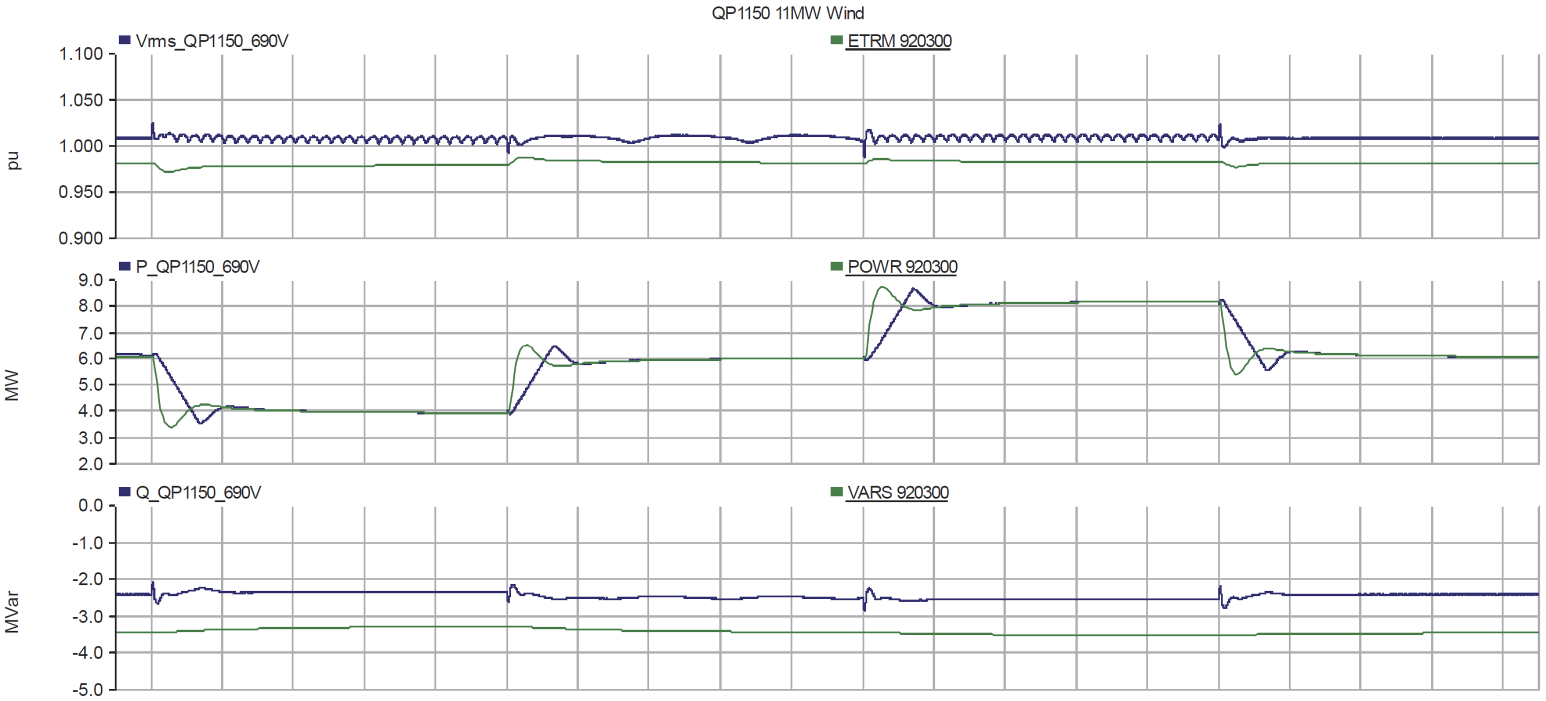
# Plant Aggregate Model Development and Deficiency Checks – Example Case 1

## Issue

- ISO: Wind turbine PSCAD model machine terminal voltage – blue trace exhibits unacceptable grid frequency deviation response. (Green traces represent PSSE model response.)

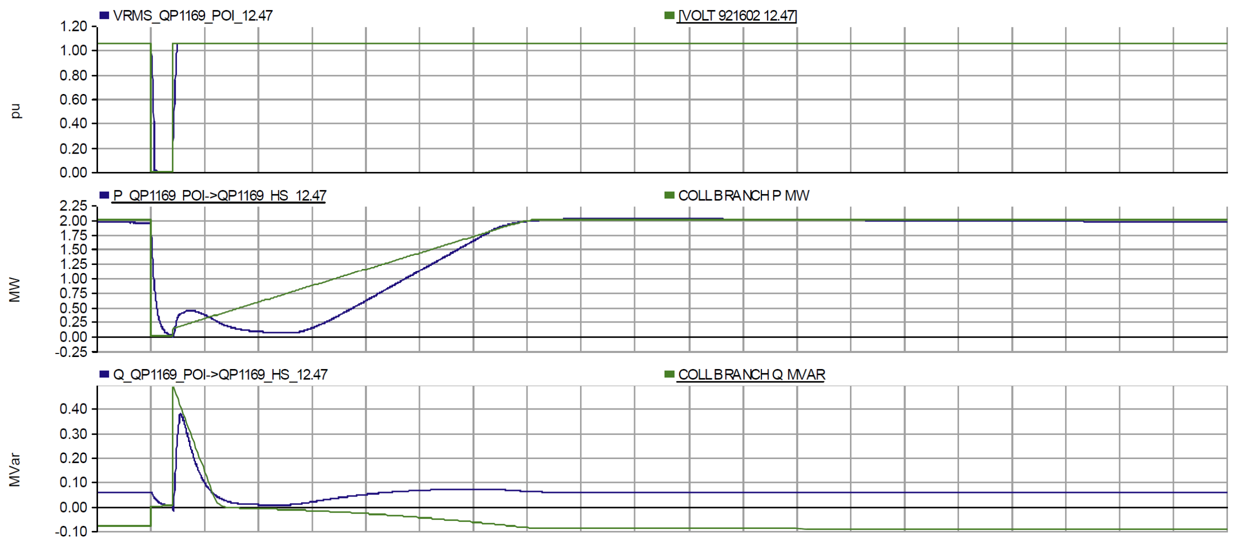
## Cause, fix and/or explanation

- OEM: The oscillations in voltage with changing system frequency are not actual stability issues or model issues. The voltage oscillation seen is as expected as the Multi-meter uses 60Hz as frequency while the system frequency changes.



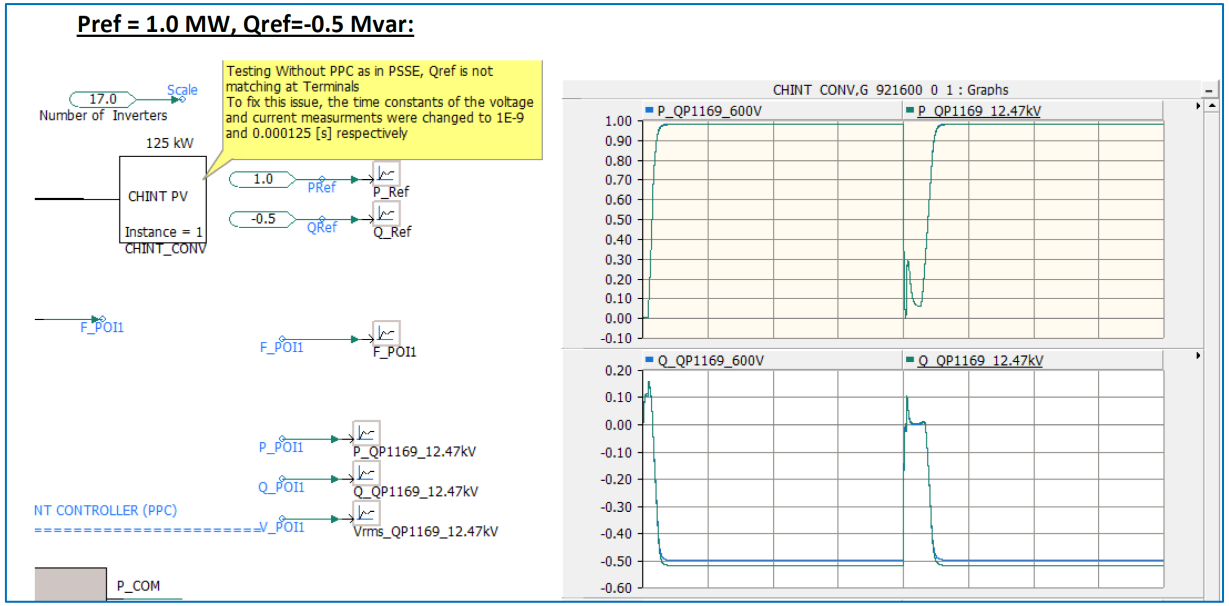
## ❑ *Issue*

▶ ISO: The inverter is unable to accurately track reactive power reference commands.




## ❑ *Cause, fix and/or explanation*

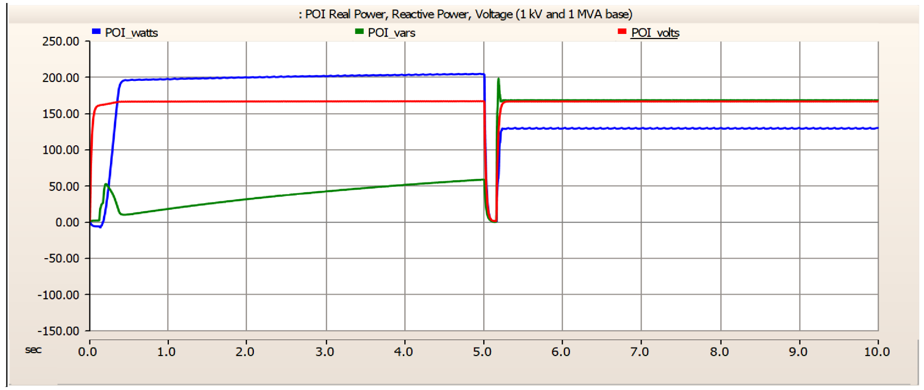
▶ EnerNex: Voltage and current measurement time constants

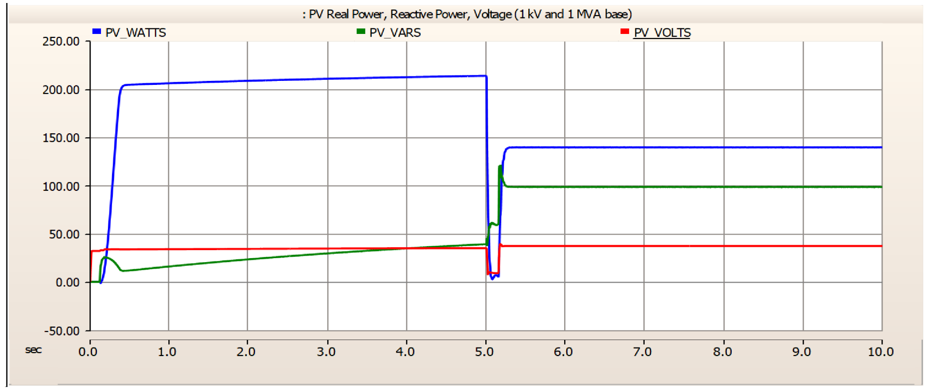


# Plant Aggregate Model Development and Deficiency Checks – Example Case 3

## ❑ *Issue*

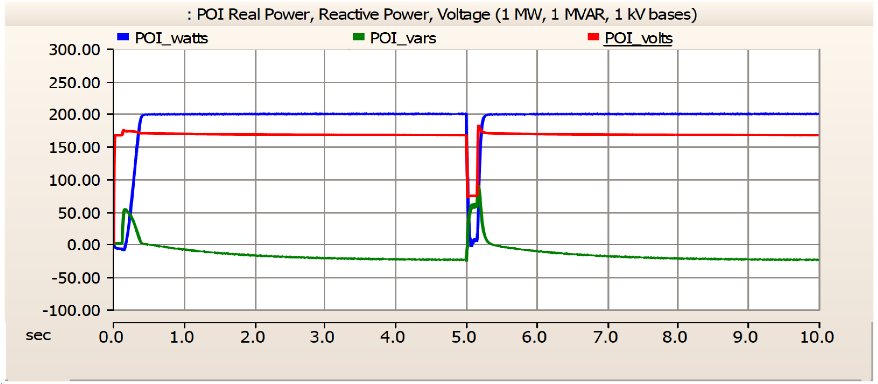
▶ EnerNex: for PV only case, P does not recover after fault.

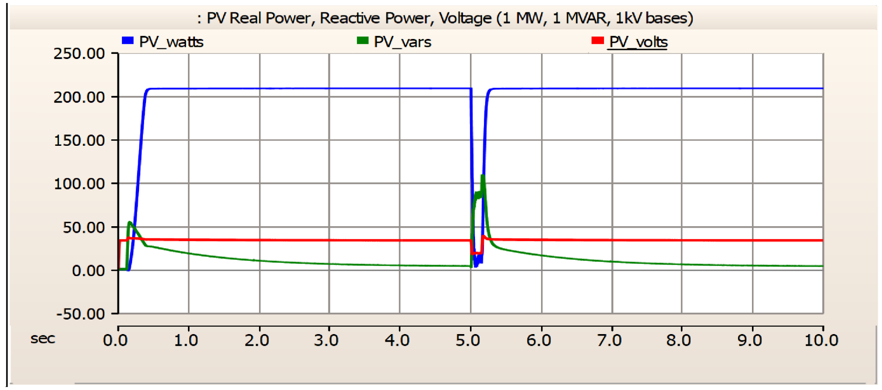



## ❑ *Cause, fix and/or explanation*

▶ Developer: updated PPC parameters

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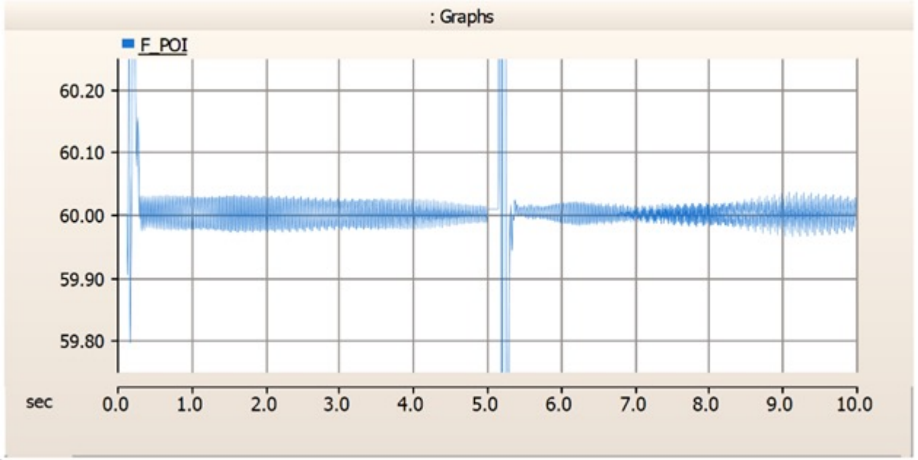
# Plant Aggregate Model Development and Deficiency Checks – Example Case 3

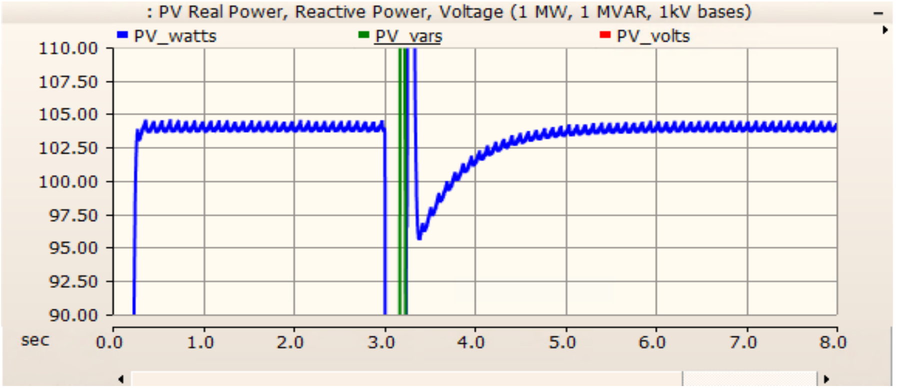
❑ *Issue*

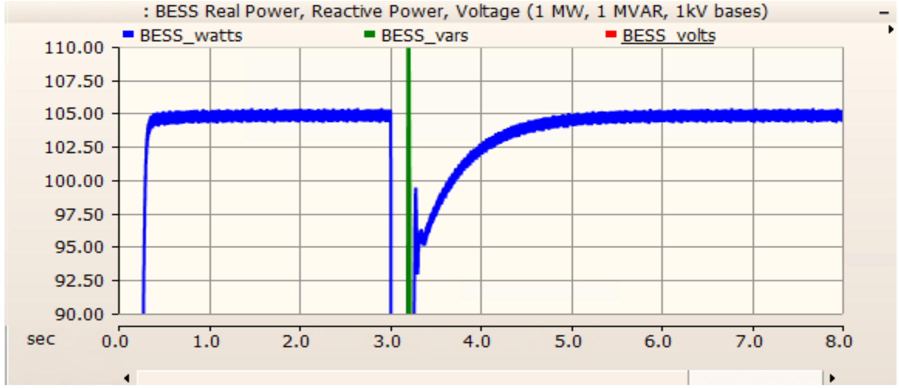
▶ EnerNex: Frequency and active power oscillations




❑ *Cause, fix and/or explanation*

▶ Developer: Modeling artifacts that can be ignored. Typically, this is caused by voltage at the terminals out of limits or simulation time step too long

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# Gaps and Challenges of Simulation Modeling of IBR Plants

- ***Model Parameterization:*** *EMT models comprise hundreds of parameters. Challenges:*
  - Limited or outdated documentation.
  - Identification of user-settable vs built-in parameters.
  - Model setup for different operating scenarios.
  - OEM default settings vs TSO guidelines, recommendations, or requirements for plant performance.
- ***Model Deficiencies:*** *The complexity of EMT models often leads to unexpected deficiencies. Challenges:*
  - Often requires comprehensive testing.
  - Timelines and Submissions.
    - A tip from NERC: *"Please don't leave it until 1 week before a submission deadline! Everyone is busy, and the work can be complex. Line up resources months in advance if possible"*
    - TSO: *"… Please review the model, then provide a package revision, by June 27."* Email Sent: Friday, June 23, 2023 2:40 PM
- ***Model Traceability:*** *Models are being constantly upgraded based on bug fixes or new features for real product.*

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# Thanks!

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