Oak Ridge National Laboratory

Advanced High-Fidelity Lumped EMT Grid Modelling & Comparison

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Overview

Problems

- Existing **TS** models do not adequately represent grid dynamics with higher penetration of renewables
- Recent reliability concerns not identified through TS models (eg, IRPTF studies)
- Non-existence of EMT models of grids

Objectives	Approach
High-fidelity **EMT** models of grids	Conversion from standard utility grid models Data-driven models Integrated model development
Evaluate contingencies and refine	Typical events: (i) generator loss, and (ii) line faults Update models and refine parameters

PSCAD
High-fidelity power electronic and component models, and portion of grid models to develop high bandwidth advanced control methods

←

PSS®E
Existing utility-scale grid models

NERC – North American Electric Reliability Corporation
IRPTF – Inverter-based Resource Performance Task Force
TS – Transient Stability
EMT – Electro-Magnetic Transient
PSCAD, PSS®E – Simulation tools

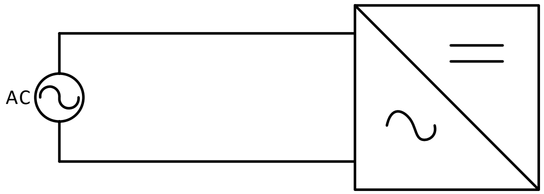
Traditional Approaches & Challenges

Power electronics' control system stability assessment

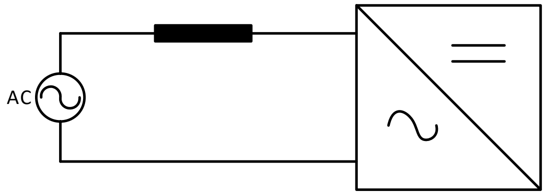
- Stiff grids represented by ac sources
- Weak grid represented by ac sources in series with impedance

Challenges

- Control interactions inadequately represented
- Non-linear dynamics inadequately captured
- High bandwidth control systems' stability inadequately studied



Stiff grid



Weak grid

ac – Alternating Current

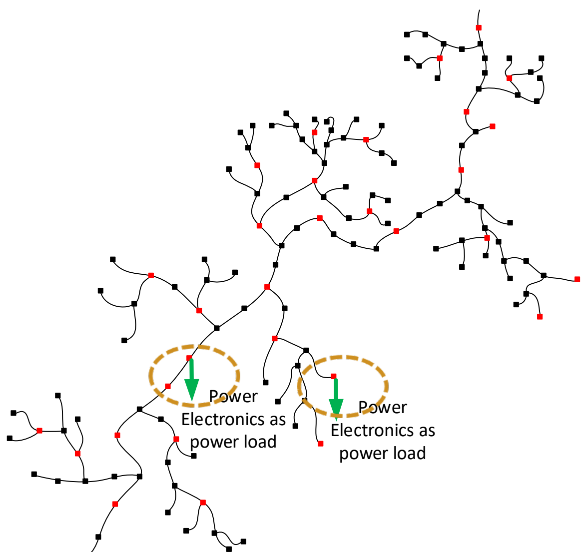
Traditional Approaches & Challenges

Large system study

- Power electronics equipment represented by a simplistic power source
- Complex models represent outer-loop control dynamics

Challenges

- Inadequate representation of power electronics resulting in limited understanding of impact of bulk power system faults and the corresponding response from power electronics
- Resilience and reliability study limitations



ac – Alternating Current

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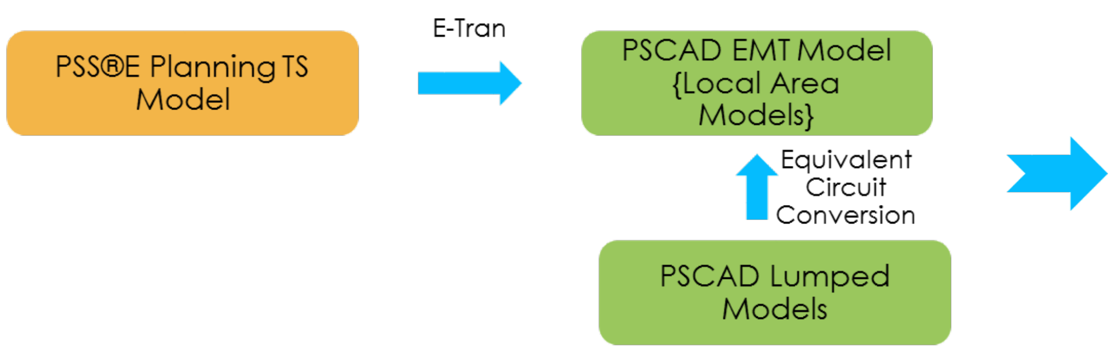
EMT Model of Grid

Voltage dynamics

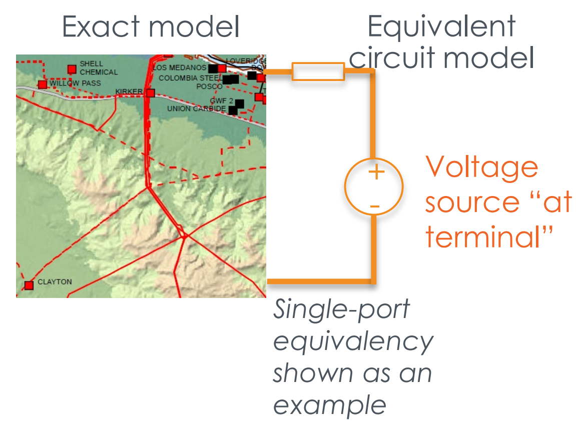
- Captured largely by the local behavior of the system near an equipment (eg, power electronics equipment)
- E-Tran tool utilized to convert existing TS grid model to EMT grid model

Local area model

- Extraction of information based on available TS model
- Nodes of interest selected from the TS model
- Voltage dynamics adequately represented



Local area dynamic model



*California Energy Commission https://www.energy.ca.gov/maps/infrastructure/3P_Enlg.pdf

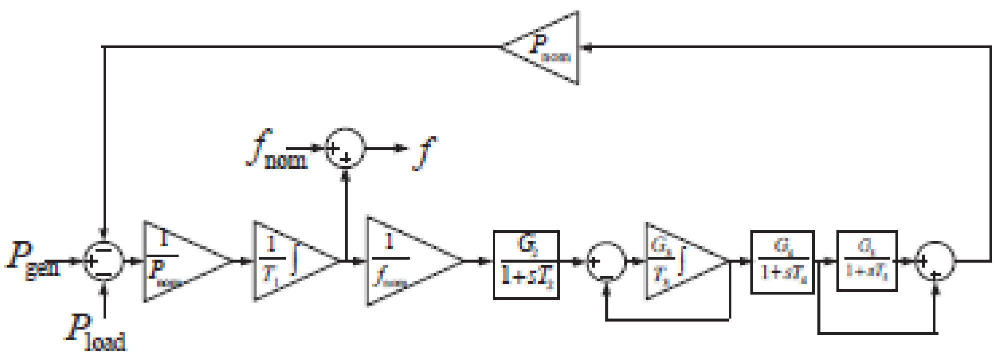
EMT Model of Grid (contd..)

Frequency dynamics

- Captured by generators and machines present in the system
- Data-driven approach chosen to provide overall dynamics of the grid (lumped model)

Lumped dynamic model

- Generator governor-based model of grid
- Data utilized from publicly available information on the grid
- Frequency dynamics adequately represented



Lumped dynamic model based on WSIEG1*

* S. Debnath and J. Sun, "Fidelity Requirements with Fast Transients from VSC-HVdc," IECON 2018 - 44th Annual Conference of the IEEE Industrial Electronics Society, Washington, DC, 2018, pp. 6007-6014.

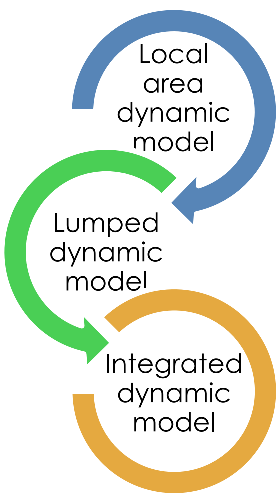
EMT Model of Grid (contd..)

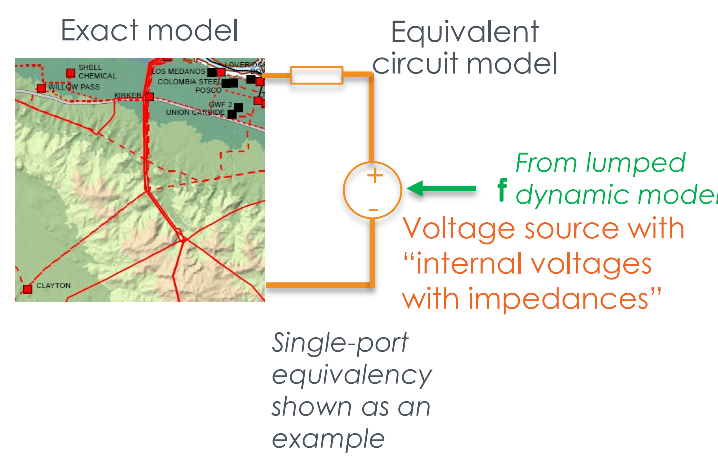
Voltage and frequency dynamics

- Benefits of power electronics equipment captured
- Unbalanced faults and other contingencies studied

Integrated dynamic model

- Combine local area model with lumped dynamic model
- Voltage source "at terminal" converted to "internal voltages with impedances"





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EMT Model of Grid (contd..)

Challenges with conversion tool

- Some exciter models are not well represented in PSCAD
- Governor absence in PSCAD leads to instability
- Negative resistance and impedance in equivalent circuit models lead instability
- HVdc models are converted to stiff sources with fixed frequency

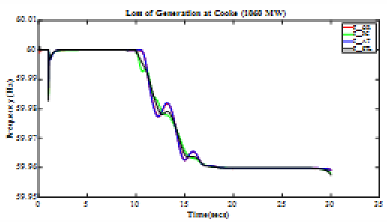
Solutions

- Use of positive resistances and impedances do not significantly alter the voltage dynamics
- Internal control mechanisms can be added to the HVdc models in PSCAD to incorporate dynamic behavior

Contingency Events

Frequency event

- Loss of generation
- Inclusion or removal of loads



Primary frequency reserves

- Reserves held in each interconnection based on NERC guidelines
- Provide support during frequency events
- Governor-based control typically present in generators

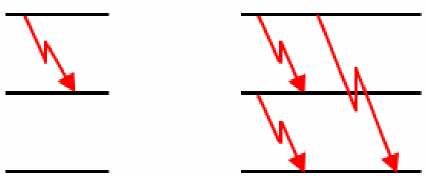
Value proposition for power electronics' system control

- Reduced reserve requirements with fast frequency support from power electronics equipment

Contingency Events

Voltage event

- Unbalanced faults
- Balanced three-phase faults



Value proposition for power electronics' system control

- Provide continuity of operations under external disturbances
- Support grid through reactive power or harmonic power

Contingency Events (contd..)

Contingency identification criteria

- NERC criteria for frequency deviation (eg, 36 mHz deadband utilized in Eastern Interconnection)
- Voltage violations: 10% deviation*
- 6 contingencies identified in total

Examples

- Pittsburg, California
- Victorville, California

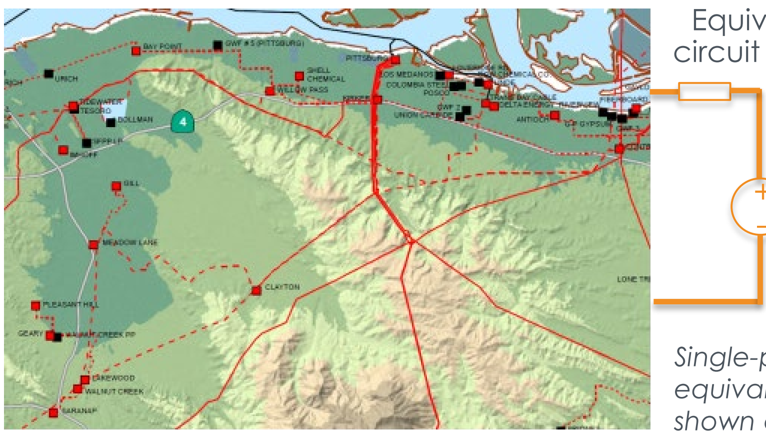
Contingencies Type	Lost Generation (MW)	Location of Interest	Voltage Magnitude Deviation	Frequency Deviation
L-L faults near LUGO	None	Victorville	14.96%	N/A
L-L faults near SERRANO	None	Victorville	12.53%	N/A
L-L faults near GATES	None	Pittsburg	12.5%	N/A
TEVA TR generator loss	1470.172	Victorville	N/A	0.08
Palo Verde generator loss	2756	Victorville	N/A	0.16
HAYNES3 generator loss	804.4	Pittsburg	N/A	0.05

* North American Electric Reliability Corporation, "1,200 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report," 2016.

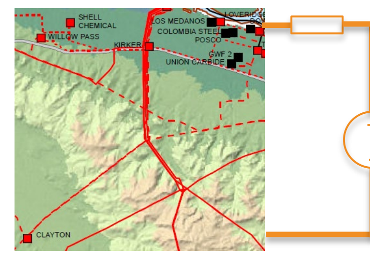
Validation Studies

Reference model

- Larger local area model that encompasses the contingencies and many more buses



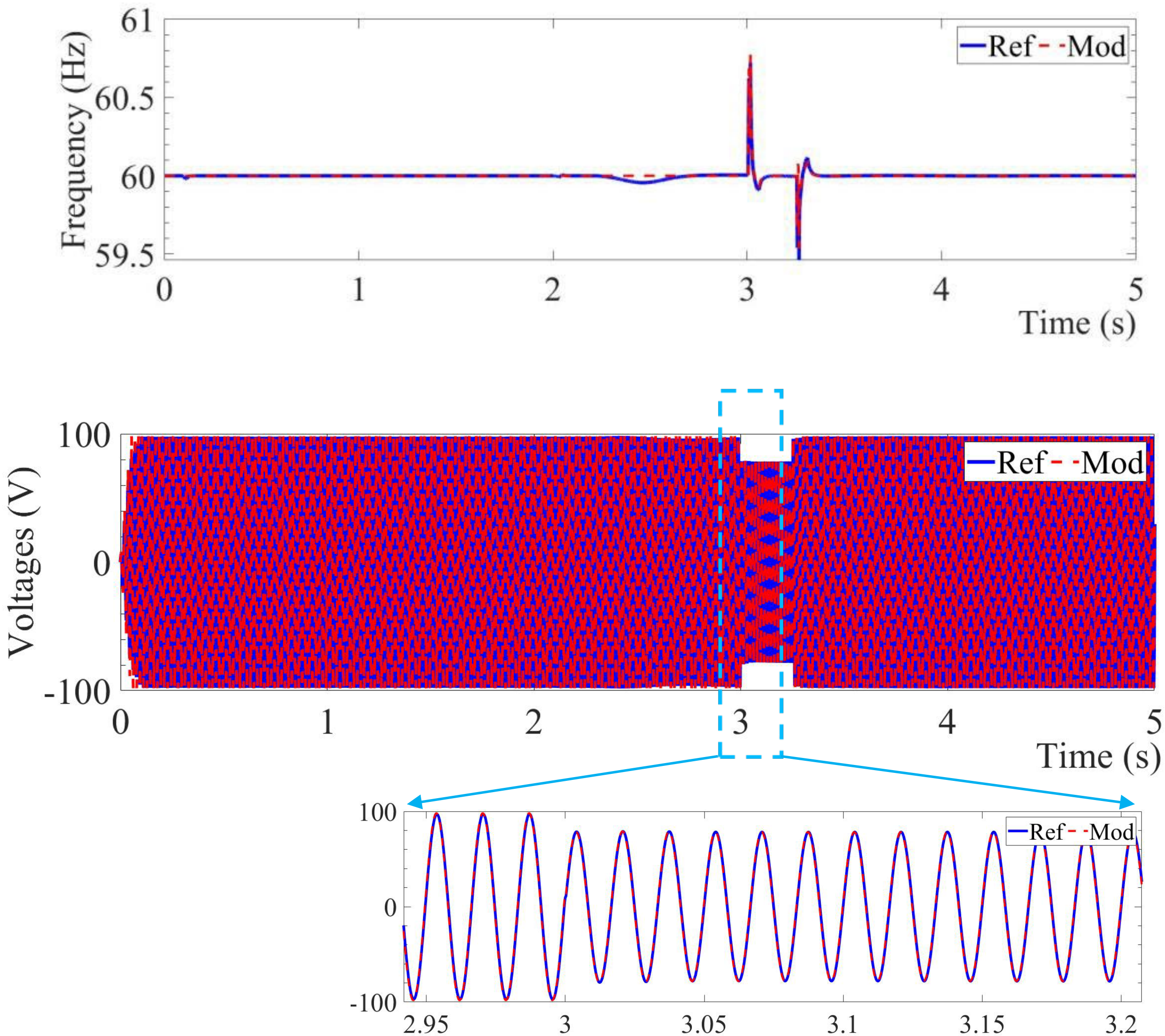
Reference model



Developed model

*California Energy Commission
https://www.energy.ca.gov/maps/infrastructure/3P_Enlg.pdf

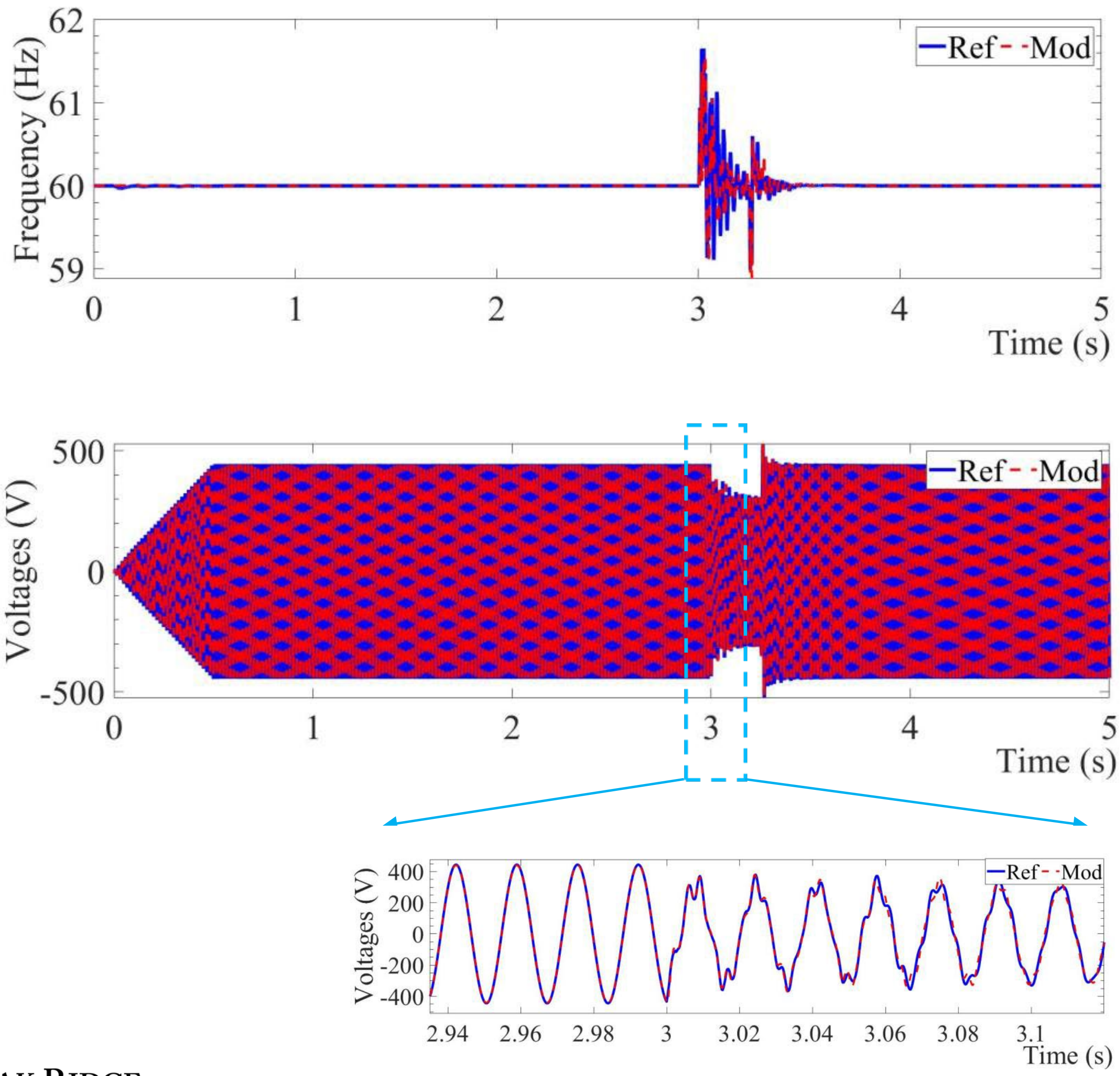
Validation Studies: Simulation Results



Line-to-line fault case study at Pittsburg

- Developed model closely follows the reference model

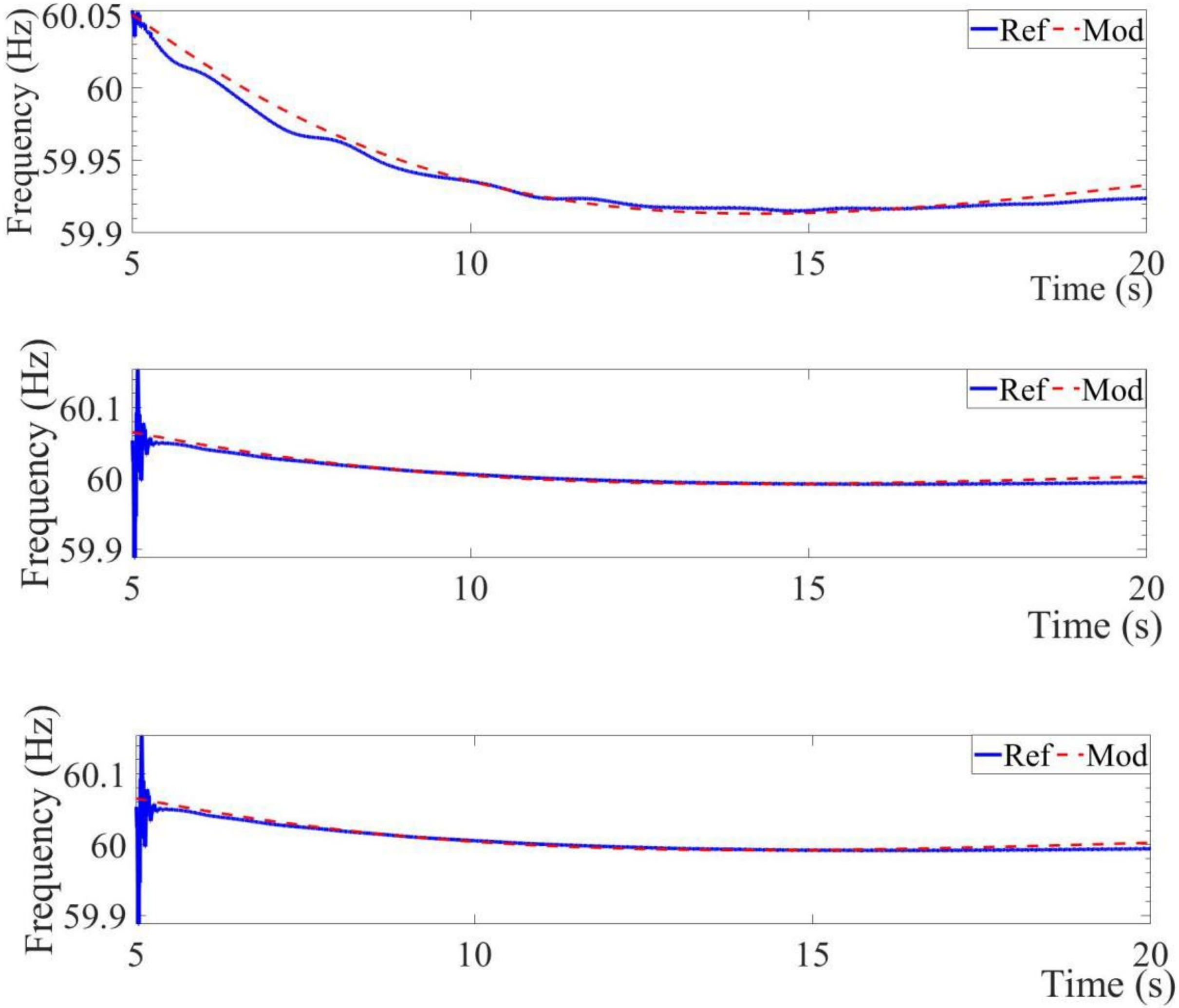
Validation Studies: Simulation Results



Line-to-line fault case study at Victorville

- High-frequency dynamics observed are well represented in the developed model

Validation Studies: Simulation Results



Generator loss studies

- Dynamics are well represented by the data-driven model

Conclusions

EMT high-fidelity grid model development method

- TS to EMT conversion using conversion tool and data-driven approaches

Conversion tool concerns highlighted

- Mitigation methods proposed

Validation with respect to use cases

- Results show adequate match

Potential applications

- Study new power electronic equipment's control system
- Reliability and stability studies in grids with high penetration of power electronics

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