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MODELLING APPROACHES AND STUDIES OF THE IMPACT OF DISTRIBUTED ENERGY RESOURCES ON THE RELIABILITY OF BULK ELECTRIC SYSTEM

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OUTLINE

- MOTIVATION
- DISTRIBUTION SYSTEM AND DER MODELING APPROACHES
- CASE STUDIES & FINDINGS
- CONCLUSION
- OTHER RELATED WORK

MOTIVATION

PURPOSE OF THE STUDY

- Distribution System connected energy resources are on the rise.
- Most of the commercially available tool use an aggregated modelling approach for distribution system connected resources for planning studies.
- Aggregated modelling approach while having the advantage of computational efficiency, have shortcoming like:
  - Inadequate representation of distribution networks and single-phase DER present in the distribution network.
  - Crude assumptions on the DC circuit and Phase Locked Loop (PLL) that might be crucial for maintaining overall stability of DER themselves.
  - Insufficient representation of the variations in the response of DER due to the differences in their local voltage. The differences in DER local voltages are related to their various localities in the distribution system caused by the operation of line regulators, switched capacitors, and loading of the distribution system.
  - Insufficient knowledge on the operational impact of the distribution system.

TRANSMISSION INTERESTS

BULK SYSTEM RELIABILITY PERSPECTIVE

Undervoltage Trip

- Multiphase transmission faults results in wide area undervoltage
- DER can trip before transmission fault cleared in ~100 ms due to perceived under voltage
- Fault-Induced Delayed Voltage Recovery of greater than 2 s can lead to more DER tripping

Frequency Trip

- Catastrophic islanding of interconnection can result in frequency based tripping of DER
- Need for Black start

DISTRIBUTION UTILITY INTERESTS

LOCAL SYSTEM RELIABILITY PERSPECTIVE

Safety of lineworkers working on hot primary lines exposed to arc flash risk.

Concern is: calorie rating of personal protective equipment vs. duration of nearby arc flash

If DER sustain and system becomes "islanded", would DER feed an arc fault until they trip?

How low do arcs faults drive feeder voltage, e.g. < 30%?

Some distribution engineers are concerned anti-islanding won't work in all scenarios (esp. mixed DER on a feeder):

If DER could sustain an island, then to avoid out-of-phase reclose, DER should trip prior to distribution recloser timing. What if islanding detection fails?

Similar concern for Distribution Automation to avoid reclosing into an island

System Protection

For feeder-level faults, distribution system protection engineers would want DERs to avoid desensitizing existing relay schemes by entering "momentary cessation" mode immediately

How do DERs interfere distribution system protection?

MODELLING APPROACHES FOR DISTRIBUTION SYSTEM AND DERS

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DISTRIBUTION SYSTEM AND DER MODELING APPROACHES FOR BPS PLANNING STUDIES

Aggregated Modeling

- Distribution system is represented by a substation transformer, an equivalent feeder, an equivalent load, and an aggregate steady-state/dynamic DER model.
- Primary examples are WECC's Composite Load Model with Distributed PV (CMPLDWG). Dynamic DER models include WECC's PVD1 and EPRI's DER_A, etc.

Pros
- Represents the aggregated average response of all the loads and all the DERs in the distribution system
- Models can be directly attached to conventional positive-sequence transmission system simulators

Cons
- Difficult to parameterize the models especially for protection settings
- Cannot capture oscillations and interactions/instability which may propagate into the transmission system

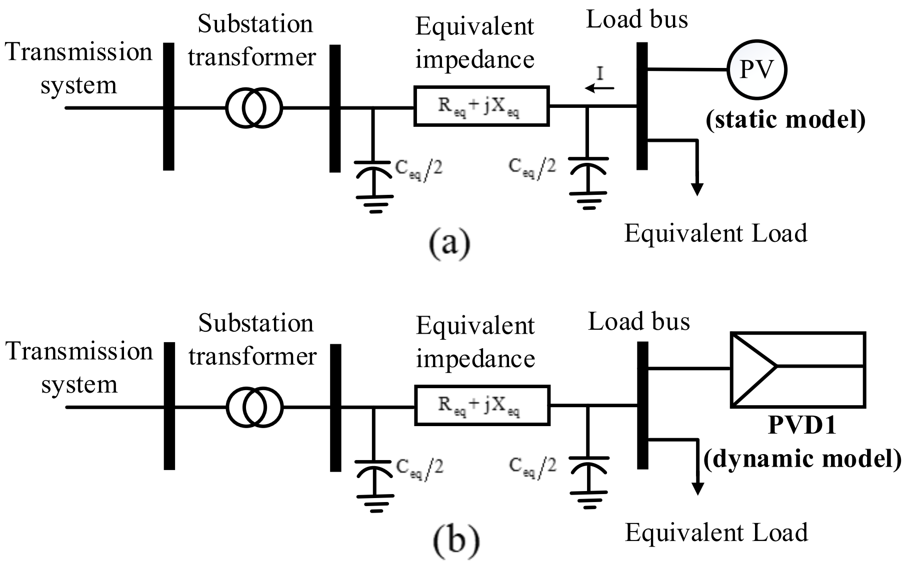


Fig: aggregated steady-state (a) and dynamic (b) model of the distribution system and distributed PV system.

DISTRIBUTION SYSTEM AND DER MODELING APPROACHES FOR BPS PLANNING STUDIES

Full Modeling

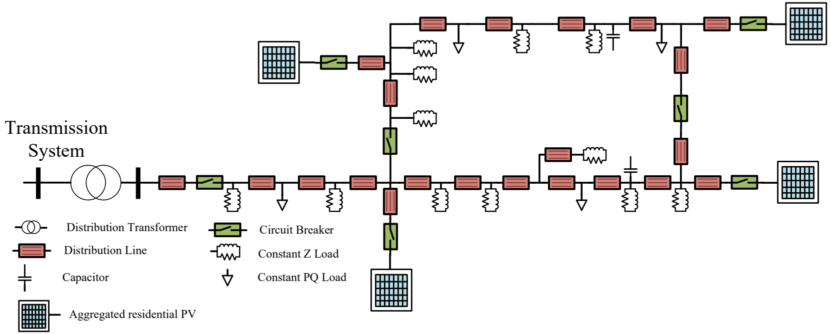
The distribution system and individual DERs are represented in a non-aggregated and detailed way to reflect their dynamic and steady-state behaviors for BPS planning and operational studies

Pros

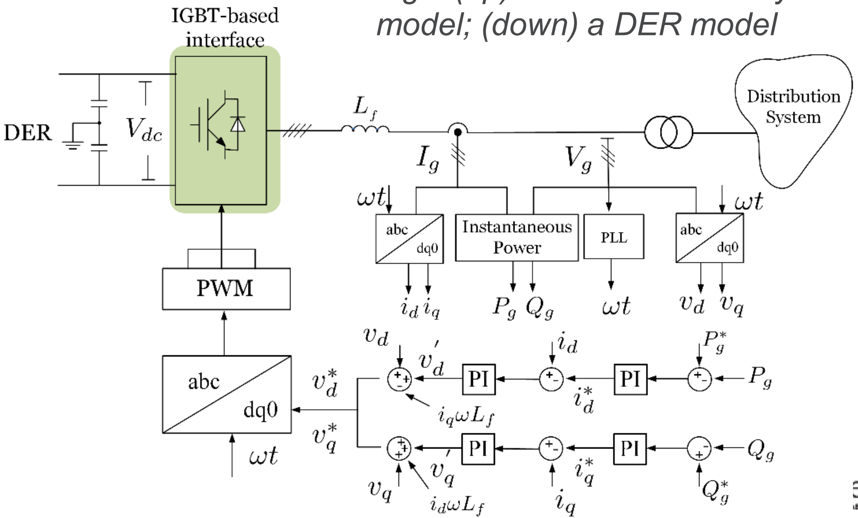
- Can faithfully represent full-spectrum response of all the loads and all the DERs in the distribution system
- No need to derive aggregate distribution system and DER model parameters

Cons

- Requires modeling of full distribution system and individual DERs that is more computationally demanding
- Requires a T&D combined modeling platform or T&D co-simulation tool to conduct BPS planning studies



Figs: (up) a full distribution system model; (down) a DER model



T&D COMBINED MODELING FOR BPS PLANNING STUDIES

T&D COMBINED MODELING

- Both transmission and distribution systems are modeled on the same platform and solved simultaneously
- Examples: MATLAB/Simulink-based or DIgSILENT/PowerFactory-based combined modeling of transmission and distribution systems

Pros

- No need to develop an interface to enable T- and D-simulators data exchange

Cons:

- Not scalable
- T-simulation tools usually model the T-system as a 3-phase balanced network, thus not simply extendable to multi-phase D-system

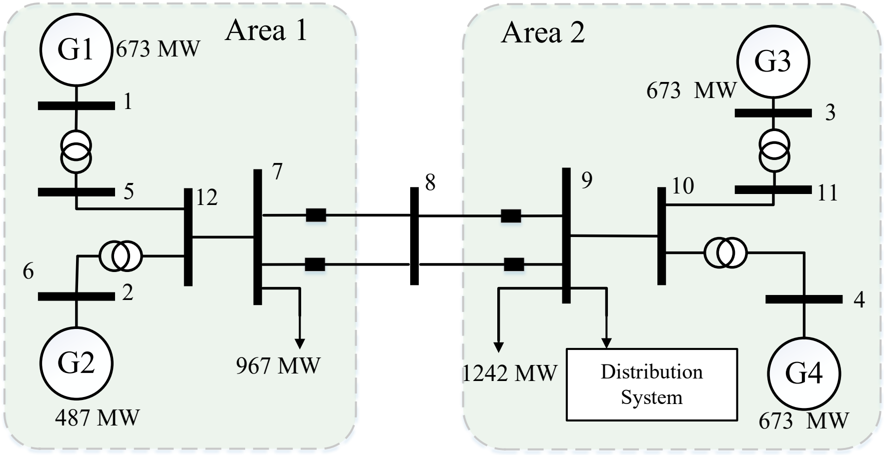


Fig: a schematic diagram of a combined transmission and distribution system

T&D CO-SIMULATION TECHNIQUES FOR BPS PLANNING STUDIES

T&D CO-SIMULATION

- A T&D co-simulation tool integrates individual transmission and distribution system simulation tools so that transmission and distribution systems can be simulated together through cyclic data exchange at the T&D interface.
- Example: Argonne’s TDcoSim that couples PSS/E (T) and OpenDSS (D)

Pros:
- Scalable to model and simulate a real-world combined T&D system
- Can overcome computational complexity issues

Cons:
- Need to develop an interface to facilitate data exchange between T- and D-simulators

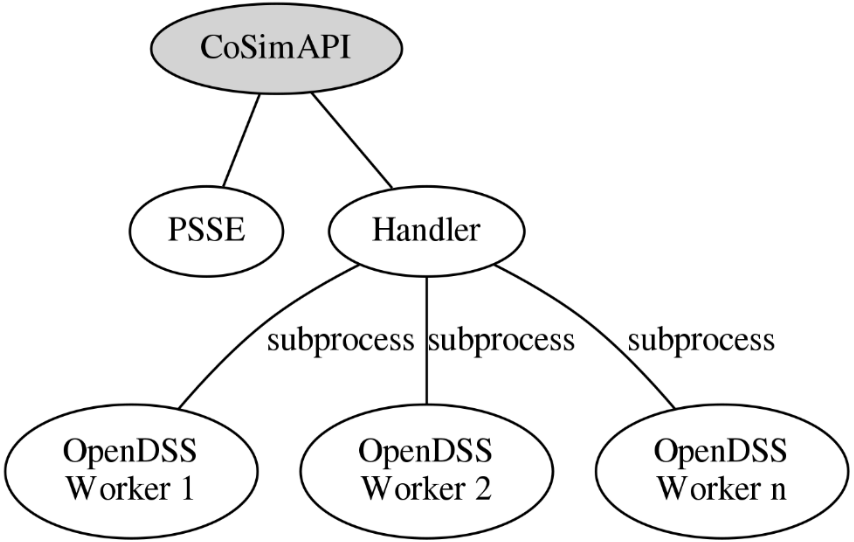


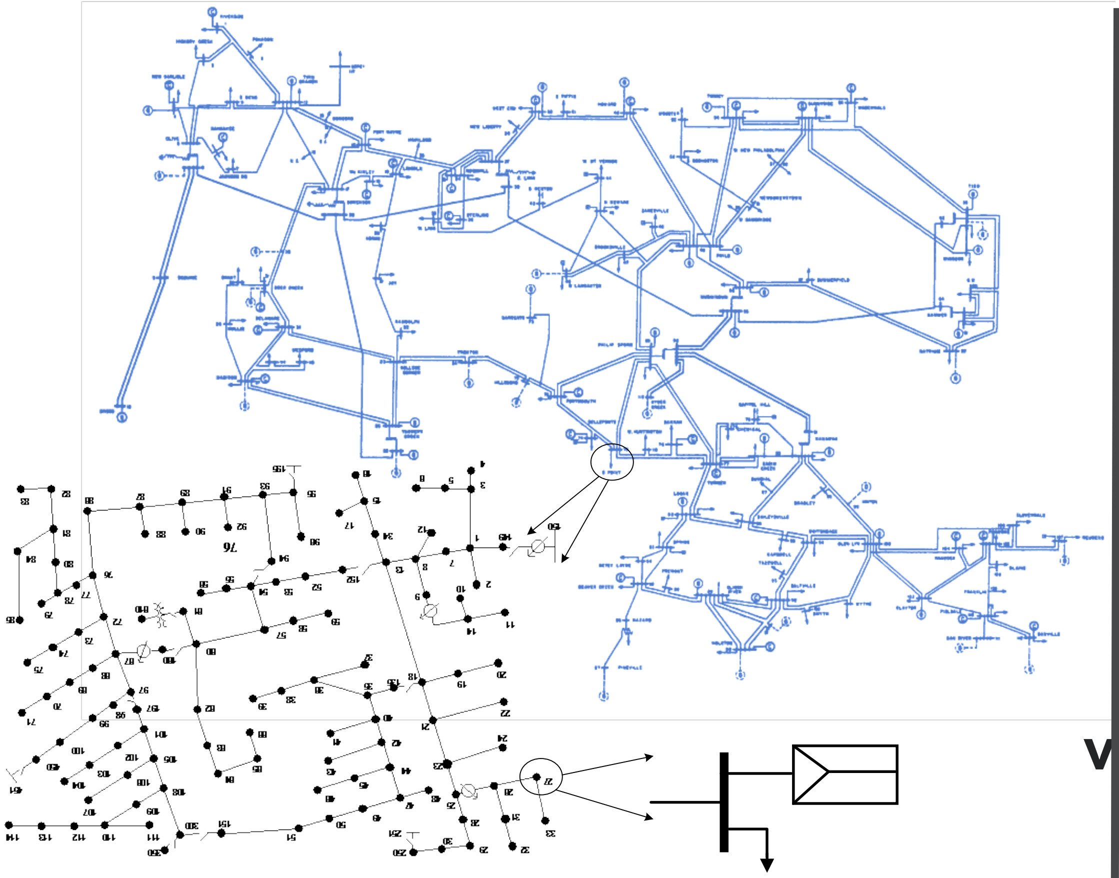
Fig: TDcoSim design

CASE STUDIES & FINDINGS

STUDIES PERFORMED

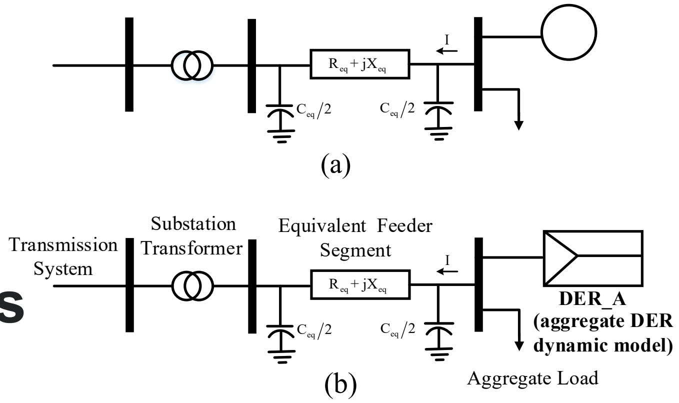
- **Study 1**: Validation of Aggregated Modeling Approaches
- **Study 2:** Impact of DER Trip or Ride Through settings on reliable operation of Bulk Electric System
- **Study 3:** Impact of Dynamic Voltage support on BES reliable operation of Bulk Electric System

SCHEMATIC DIAGRAM OF TEST SYSTEM



Full Model

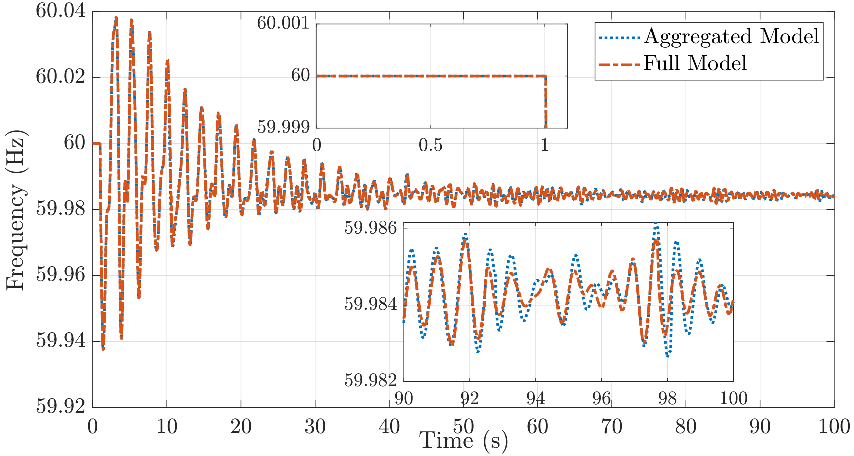
vs



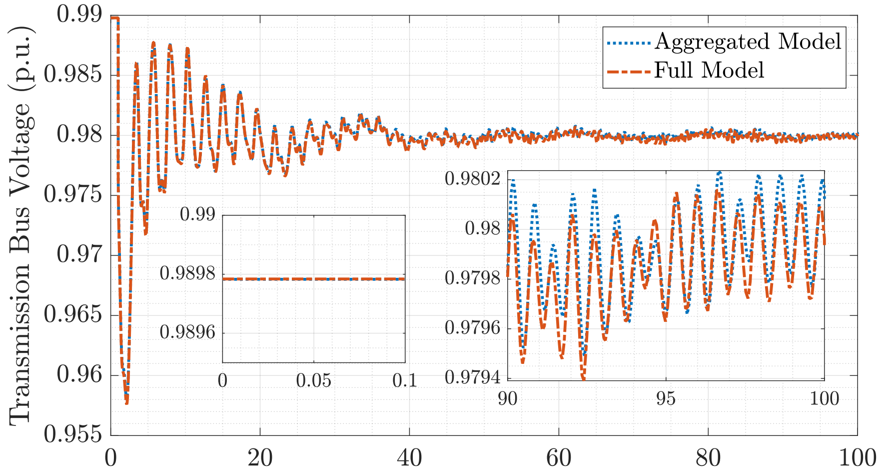
Aggregated Model

RESULTS SHOW FOR A SMALL DISTURBANCE IN THE SYSTEM BOTH THE AGGREGATED MODEL AND FULL SHOW COMPARABLE RESPONSES

Event: Loss of 50 MW Generation



Frequency Response of nearby generator

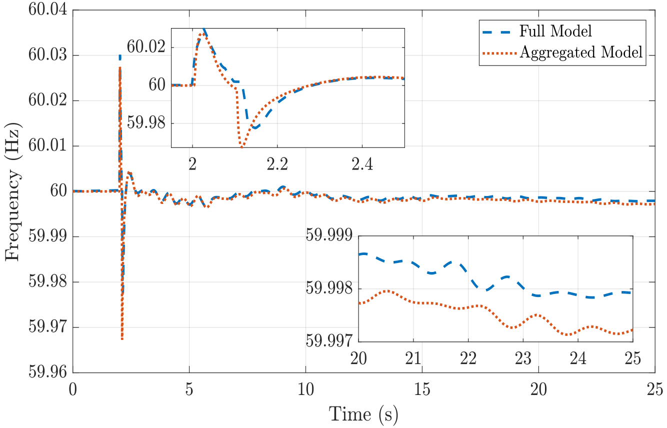


Voltage Response of nearby transmission bus

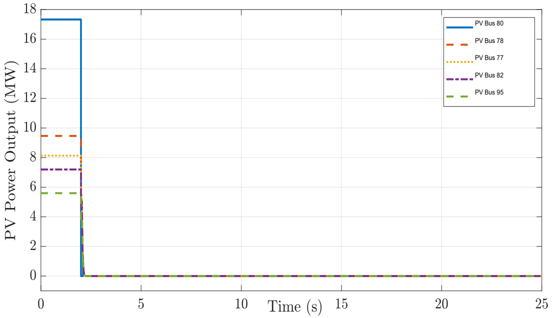
RESULTS SHOW FOR A SEVERE DISTURBANCE IN THE SYSTEM AGGREGATED MODEL AND FULL SHOW COMPARABLE DIFFERENCES IN RESPONSES

Event: 3 phase self clearing bolted fault for 6 cycles

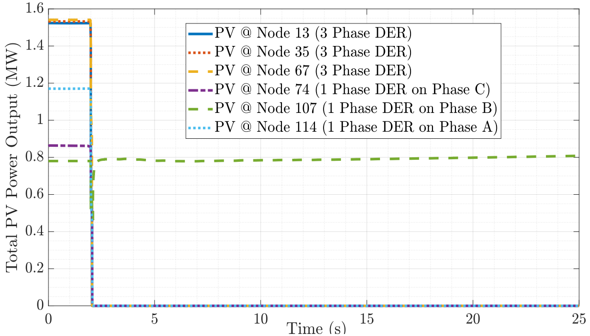
Fault location was prescreened to affect a large percentage of load in the system



Frequency Response of nearby generator



Active power output from aggregate PV models at various transmission buses

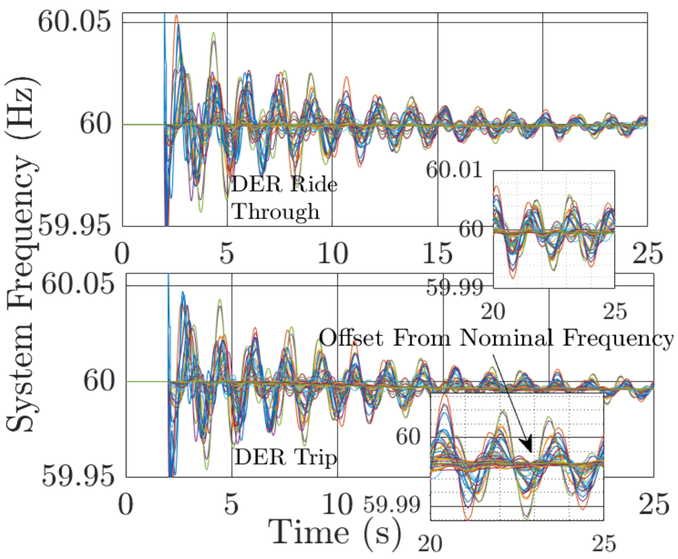


Active power output from all six individual PVs in the distribution system connected at transmission bus 77.

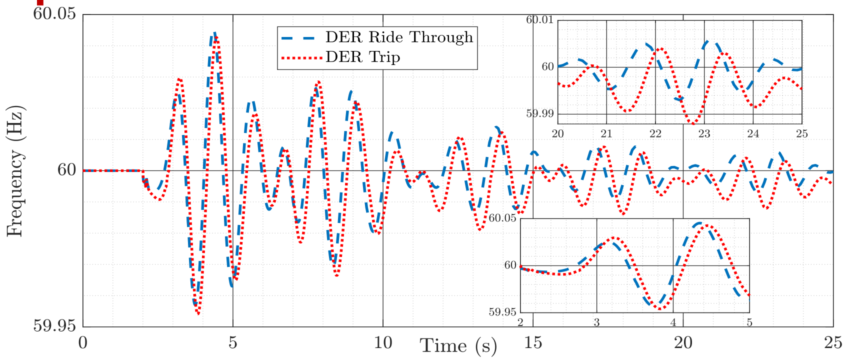
Note: Not all DERs trip with the full model

DER TRIP HAS NOTICEABLE IMPACT ON BES EVEN AT LOWER PENETRATION LEVEL

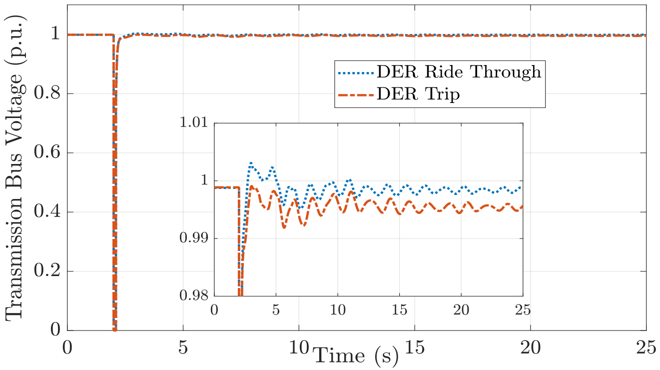
Event: 3 phase self clearing bolted fault for 6 cycles on bus 80
DER penetration level : 2% compared to BES Load



Frequency Response of all generators



Frequency Response of all nearby generator



Voltage comparison for faulted bus with DER trip and ride-through settings

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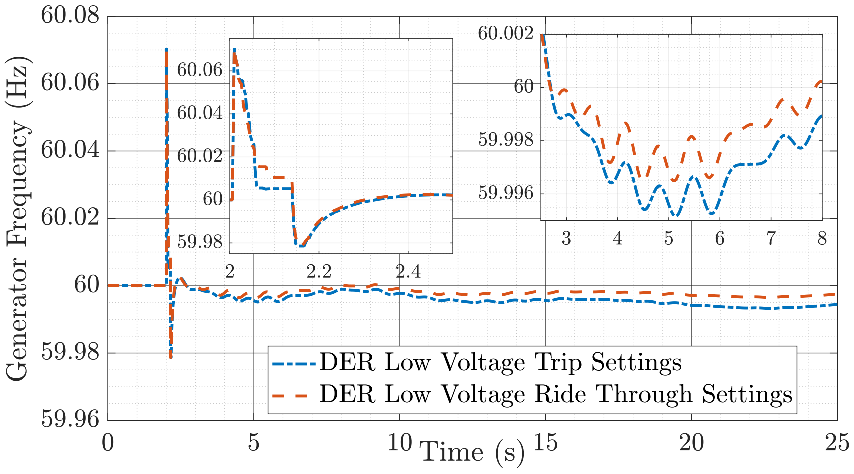
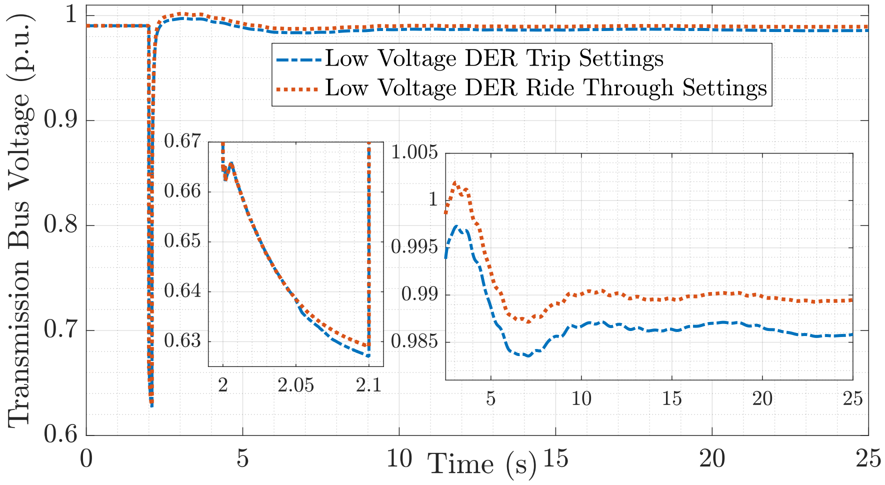
DER TRIP HAS NOTICEABLE IMPACT ON BES EVEN AT HIGHER PENETRATION LEVEL

Event: 3 phase self clearing bolted fault for 6 cycles on bus 80
DER penetration level : 11% compared to BES Load



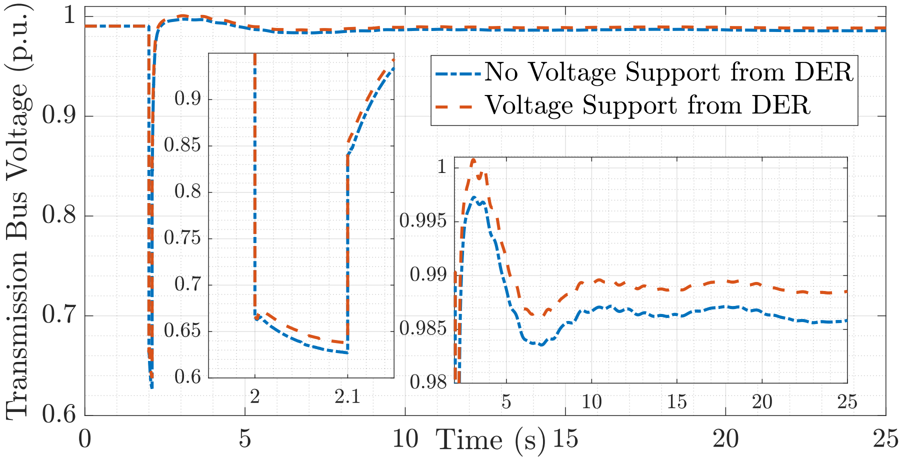
Frequency Response of all nearby generator



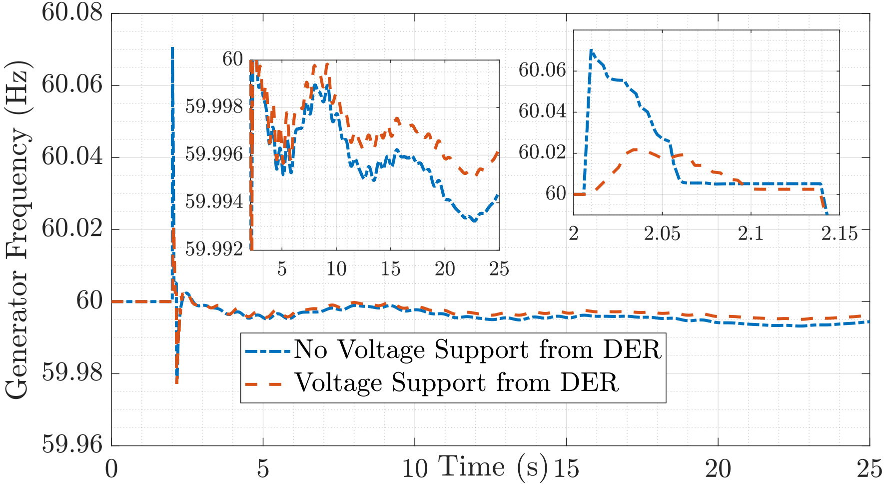
Voltage comparison for faulted bus with DER trip and ride-through settings

DYNAMIC VOLTAGE SUPPORT FROM DER SUPPORTS BES RELIABILITY

Event: 3 phase self clearing bolted fault for 6 cycles on bus 80
DER penetration level : 11% compared to BES Load



Voltage comparison for a transmission bus near fault location with/without DER dynamic local voltage support



Frequency comparison of the generator at transmission bus 80 with and without DER dynamic local voltage support.

Amount of Tripped DER without Voltage Support	Amount of Tripped DER with Voltage Support
180.19 MW	61.85 MW

CONCLUSION

FEW TAKEAWAYS

- Even though the aggregated modeling approach provides benefits in terms of **faster simulation run time and reduced complexity of the system**, the **results** obtained from these models can be **considerably different** depending on the **parameters used** for these models and the **nature of disturbances** in the system. The differences can be **critical in making planning decisions** at higher DER penetration level.
- **DER ride through** settings play a critical role in overall **system stability and reliability** following system disturbances.
- With the **local voltage support**, DER can ride through the fault with **less number of DER trip**ping, which eventually results in **better system voltage and frequency recovery** as opposed to when DER do not support local voltages.

OTHER RELATED WORK

SUPPORTING NERC'S NEW WORKING GROUP ON "SYSTEM PLANNING IMPACTS OF DER (SPIDER)"

- NERC SPIDERWG addresses aspects of key points of interest related to system planning, modeling, and reliability impacts to the Bulk Power System (BPS)
- One of the top priority initiatives at NERC
- Argonne supports all 4 subgroups with our new **T&D Co-simulation** Platform
  - Steady-state and dynamic simulations for transient stability and disturbance ride-thru studies
  - Scalability to model realistic interconnections and distribution networks
  - Flexibility to implement DER interconnection standards
  - Flexibility to implement advanced DER control functions

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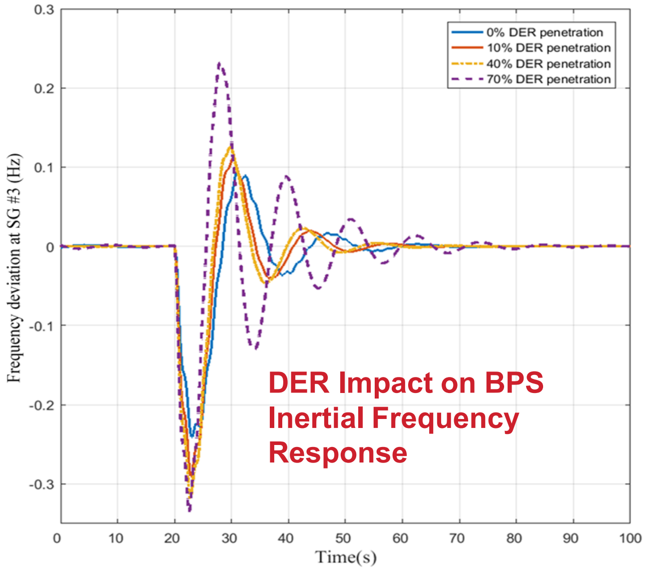

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