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Power System Technical Performance

10215

Transformer Configuration Impacts on Transient Phenomena in Inverter-Based Resource Dominated Distribution System

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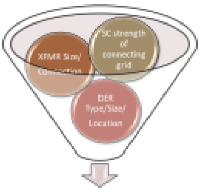
Motivation

- Electric grid is evolving from a passive to an active network
- IBRs are changing the traditional protection and control practices



Overvoltages	Open-Phase Detection	Ferroresonance
• Ground-fault and load-rejection overvoltages, especially during unintentional island conditions	• Problems with voltage regeneration at transformer high-side	• Possible in low-loss systems with non-linear transformers magnetizing L and system C • Highly non-linear

Transient overvoltage is a temporary short-duration highly-damped, oscillatory overvoltage that may be associated with switching, faults, lightning strike or other nonlinear events

Need for electro-magnetic transient studies

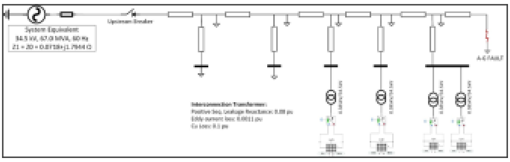
Method/Approach

- Developing a framework for utilities to undertake EMT studies with increasing DER penetration
- Corroborating previous research based on real-world case study using utility required smart-inverter settings (based on IEEE 1547-2018)
- Investigate challenges with simulation studies and use of OEM black-box models

Objects of Investigation

- 34kV real-world feeder model from detailed distribution modeling software
- Network reduction and model conversion to EMT platform (represented as pi sections)
- Aggregation of loads, identification of DER locations and OEM inverter-model integration
- Manufacturer transformer saturation curves and surge arrester characteristics

Experimental Setup & Test Results



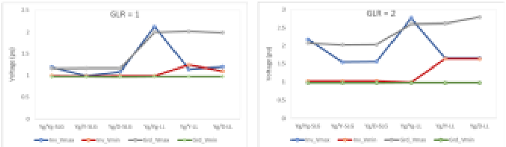
System one-line diagram in EMTP

- Transformer Connections:
  - Yg/Yg, Yg/Y, Yg/Delta
- Load Connections:
  - Phase-Ground, Phase-Phase
- Generation-Load Ratio (GLR)
  - 1 and 2

Case Number	GSU Connection (kV/MV)	Load Type	Generation Load Ratio (GLR)	Reference
[illegible]	Yg-Yg	[illegible]	1	Yg/Yg-SLG
[illegible]	Yg-Y	[illegible]	1	Yg/Y-SLG
[illegible]	Yg-Delta	[illegible]	1	Yg/D-SLG
[illegible]	Yg-Yg	Delta	1	Yg/Yg-LL
[illegible]	Yg-Y	Delta	1	Yg/Y-LL
[illegible]	Yg-Delta	Delta	1	Yg/D-LL

Case Number	GSU Connection (kV/MV)	Load Type	Generation Load Ratio (GLR)	Reference
[illegible]	Yg-Yg	[illegible]	2	Yg/Yg-SLG
[illegible]	Yg-Y	[illegible]	2	Yg/Y-SLG
[illegible]	Yg-Delta	[illegible]	2	Yg/D-SLG
[illegible]	Yg-Yg	Delta	2	Yg/Yg-LL
[illegible]	Yg-Y	Delta	2	Yg/Y-LL
[illegible]	Yg-Delta	Delta	2	Yg/D-LL

Test cases for overvoltage study



Maximum and minimum peak voltage at inverter- and grid-side of interconnection transformer

Discussion

- Primary-side SLG fault currents are limited by transformer connections
- With ride-through and trip requirements for inverters, open questions on algorithms exist
- Some solutions include: DTT, grounding transformer, negative sequence current detection, zero-sequence voltage measurements (3V0), surge arrester current monitoring

Conclusion

- Overvoltages affected by interconnection transformer connection, load connection and generation to load ratio
- Inverter islanding controls become critical in avoiding GFO/LRO
- No one connection is ideal – inherent trade-offs exist
- Simulation run-times can be high based on model complexity

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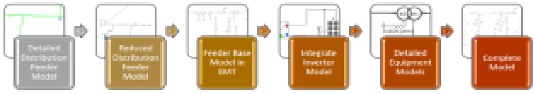
continued

Categories of Studies for TOV

- Ground fault and load-rejection overvoltages
- Open-phase detection
- Ferroresonance

Study Development : Model Fidelity

- Model fidelity is key to validating simulation results
- Important to outline study objectives, design, approximations, data sources, address limitations and result validation
- Key components of the study: feeder model, inverter model, transformer magnetizing characteristics, and surge arrester characteristics



Model Components

- 34kV utility feeder with four PV installations (2mW each)
- Upstream substation represented by Thevenin equivalent
- Constant three-phase PQ loads on the feeder
- 2.2MW DC/AC inverter for interconnection via a transformer
    - Implemented user-defined settings
    - Anti-islanding and open-phase detection activated
- Overhead conductors modelled as pi sections with impedances based on field data

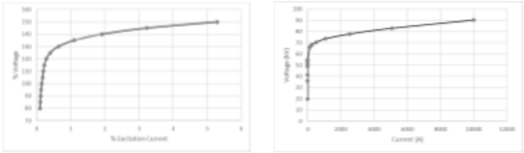


Figure 1. Transformer (left) and Surge Arrester V/I characteristics (right)

Additional Results

- Inverter open-phase detection may not always be relied upon
- For the given inverter model, no 0-seq V/I observed on high side
- Ferroresonance is a highly non-linear phenomena affected by transformer connections.
    - Generally observed in Yg/Yg, Yg/Y and Yg/Δ transformers (MV/LV)
- Overall, addition of surge arresters reduce the observed overvoltages

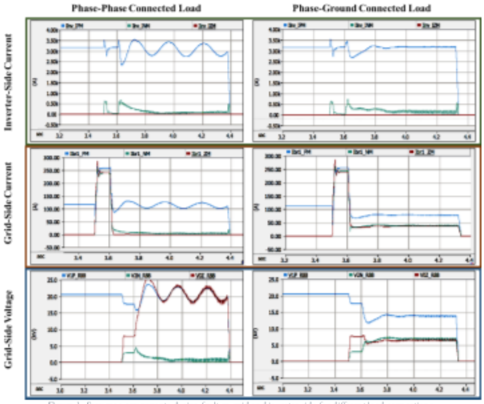


Figure 1. Sequence components during fault on grid and inverter side for different load connections

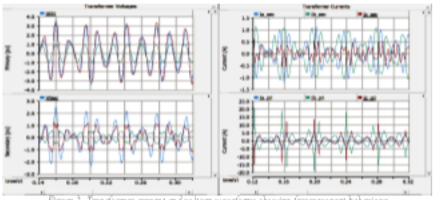


Figure 2. Transformer current and voltage waveforms showing ferroresonant behaviour

Comparison between different transformer configurations

Yg/Yg	Yg/Δ or Yg/Y
•Act as a ground source if inverter is grounded •Inverter can see the ground fault on MV side resulting in faster tripping times •Highly unbalanced voltages during fault on inverter and grid side •Generally voltage magnitudes are higher on both MV and LV side •Better open-phase detection due to inverter visibility •At risk of ferroresonance; risk lower than Yg/Δ	•No ground source on grid side •Due to the Δ-high side, SLG on MV may not be visible to the inverter •Higher MV side voltage but lower inverter-side voltage •Highly unbalanced voltages on grid side but they stay balanced on the inverter side •Slower inverter trip times and higher arrester energy •Difficult to observe open-phase due to the Δ high side •Higher risk of ferroresonance than other configurations

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