# Effective Grounding of Inverter-Based Distributed Generation

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# Outline

- INTRODUCTION:
- DEFINITIONS:
  - Effective Grounding
  - Functionally Grounded Inverters
- GROUNDING CONFIGURATIONS:
- MITIGATION METHODS:
- DEVELOPER REQUESTS:
  - Three-Wire Inverters Permitted by All Utilities
  - JU to Help with Additional Protection Design
- CONCLUSIONS:

# Introduction:

- **Barriers Introduced by The Utilities:**
  - Complete Rejection of Three-Wire Inverters on the Basis of Effective Grounding
  - Different Design Requirements for Three-Wire Inverters in Each Territory
- **Influx of Three-Wire Inverter Applications Recently Which Brought This Issue to Light**
  - Major Industry Shift to New 1500V UL Listed Inverters
    - Significant labor savings of $0.04-0.05 per watt
    - Extremely restrictive on manufacturers which may be used - Only One Manufacturer with Four-Wire
    - *Projects cannot be built without these inverters under the new incentives*
  - No Central Inverters have a Three-Wire Configuration
    - Limits entire industry to only string inverter designs
    - Power Conversion System (PCS) inverters for battery storage are all three-wire
  - Other Utility Territories (MA, CA, & IL) and a Majority of Utilities in NY Allow Three-Wire Inverters
    - Approved equipment list on ITWG website includes three-wire inverters
- **Goals of this Conversation:**
  - **Both Three-Wire and Four-Wire UL Listed Inverters Are Permitted Across the State**
  - **Agreed Upon Approaches to Interconnection Design that Mitigates Utility Concerns for Three-Wire Inverters**

# Definitions

# Definitions:

*Effective Grounding*

- **Effectively Grounded:** “An expression that means grounded through a grounding connection of sufficiently low impedance (inherent or intentionally added or both) that a ground fault that may occur cannot build up voltages in excess of limits established for apparatus, circuits, or systems so grounded.” (IEEE 62.92.1)
  - “[...] COG [coefficient of grounding] does not exceed 80%.” (IEEE 62.92.1)
  - “This value is obtained approximately when, for all system conditions, the ratio of the zero-sequence reactance to the positive-sequence reactance, (X0/X1), is positive and < 3, and the ratio of zero-sequence resistance to positive-sequence reactance, (R0/X1), is positive and < 1 [...]” (IEEE 62.92.1)
  - “In linear circuits, Class A1 [Effective Grounding] limits the fundamental line-to-ground voltage on an unfaulted phase to 138% of the prefault voltage” (IEEE 62.92.1)

- **Transient Overvoltage (TOV)**: “The temporary overvoltage associated with the operation of a switching device, a fault, a lightning stroke, an arcing ground fault on an ungrounded system, or other instigating events.” (IEEE 142-2007)

# Definitions:

*Functionally Grounded*

- **Functional Grounded PV System**: “A PV system that has an electrical reference to ground that is not solidly grounded.” (NEC 2017). Both 3-wire and 4-wire inverters are functionally grounded and do not use their ground reference for return current.
- **Advanced Energy White Paper - “Why Most Inverters Do Not Have a Solid Neutral Connection”**:
  - “Photovoltaic inverters are designed and intended to operate as balanced, 3 phase current sources. Therefore, a neutral conductor is not necessary for the export of power. Since the neutral conductor is not actually necessary, most inverters do not even have terminals for a neutral conductor.”
  - “The reason this is not offered as an option by inverter manufacturers is this modification would make it ***very difficult to comply with the UL 1741 standard.*** “
    - “The most important reason inverters do not have solid neutral connection is prevent minute, short duration imbalances in phase switching times from leading to unwanted neutral currents in the output.”
    - “Additionally, a solid neutral connection can interfere with the inverter’s ability to detect phase voltage problems, and lead to unwanted nuisance currents in the isolation transformer.”
    - “Given the difficulties associated with adding a solid neutral connection, it is worth ascertaining whether or not there is any real benefit to having a solid neutral connection in an inverter.”
- **Sungrow White Paper - “SG125HV Neutral, Safety, and Grid Connections”**:
  - “Basis of the Neutral Connection in the SG125HV: The neutral connection on grid tied PV inverters is not necessary as PV inverters are balanced 3-phase current sources, alleviating the need for a neutral connection since there are no single-phase loads connected directly to the inverter.”

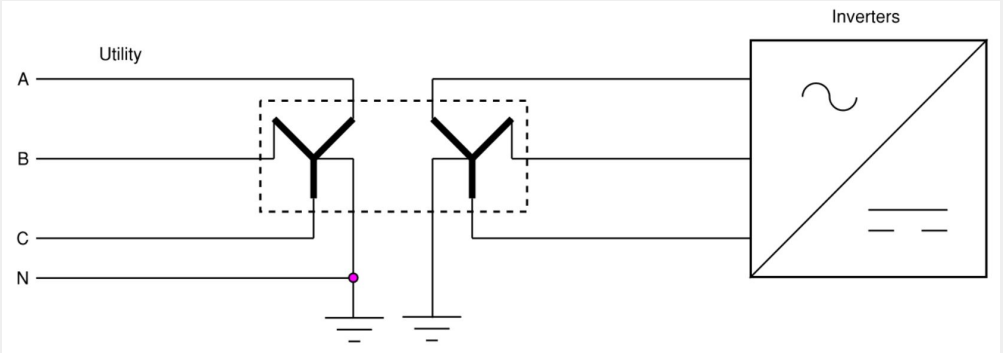
# Grounding Configurations In Current Markets

# Grounding Configurations:

*Transformer Configuration - (Yg - Yg)*

**Utilities where similar configuration is accepted:**

- MA - National Grid (< 500kW)
- MA - Eversource [NSTAR & WMECO] (< 1MW)
- NY - National Grid (< 500kW)
- NY - Orange and Rockland (4-wire inverters)
- NY - CHG&E (4-wire inverters)
- NY - NYSEG (4-wire inverters)
- NY - RG&E (4-wire inverters)




**Advantages:**

- Effectively Grounding for 4-wire inverters
- No TOV issues during single phase faults
- Provides ground source for overcurrent detection at PCC

**Current Challenges**

- Lack of wide acceptance for 3-Wire Inverters

# Grounding Configurations:

*Transformer Configuration - (Yg - Yg) w/ Grounding Bank*

**Utilities where similar configuration is accepted:**

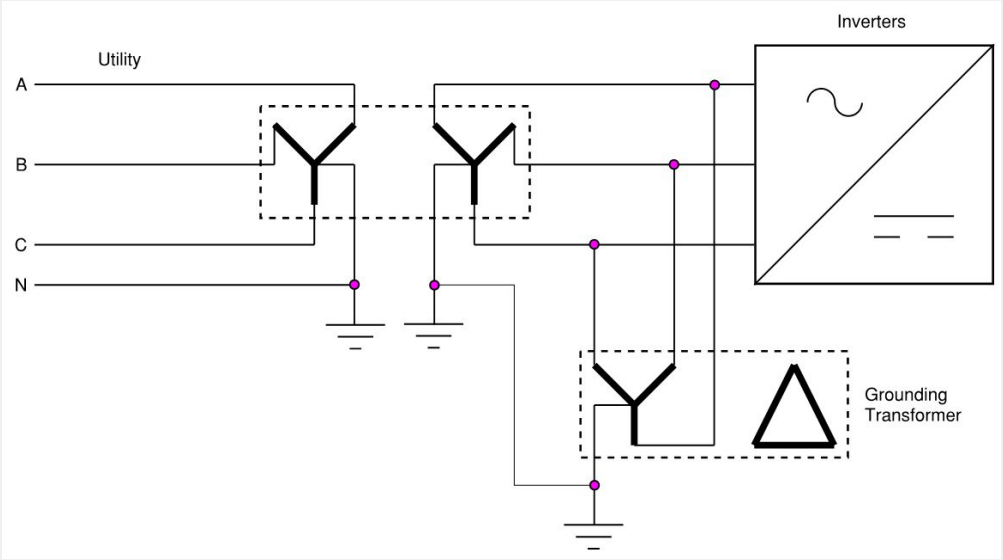
- MA - National Grid (> 500kW)
- MA - Eversource [NSTAR & WMECO] (> 1MW)
- NY - National Grid (> 500kW)
- NY - CHG&E (3-wire inverters)

**Advantages:**

- Effective Grounding for 3-wire and 4-wire string inverters that can connect to Yg transformers
- No TOV issues during single phase faults
- Provides ground source for overcurrent detection at PCC

**Current Challenges**

- Lack of wide acceptance for 3-Wire Inverters
- Desensitization of upstream overcurrent relays
    - Avoided if grounding transformer is adequately sized
- One-Off Utility Requirements



# Grounding Configurations:

*Transformer Configuration - (Yg - □) w/ Potential Neutral Grounding Reactor*

**Utilities where similar configuration is accepted:**

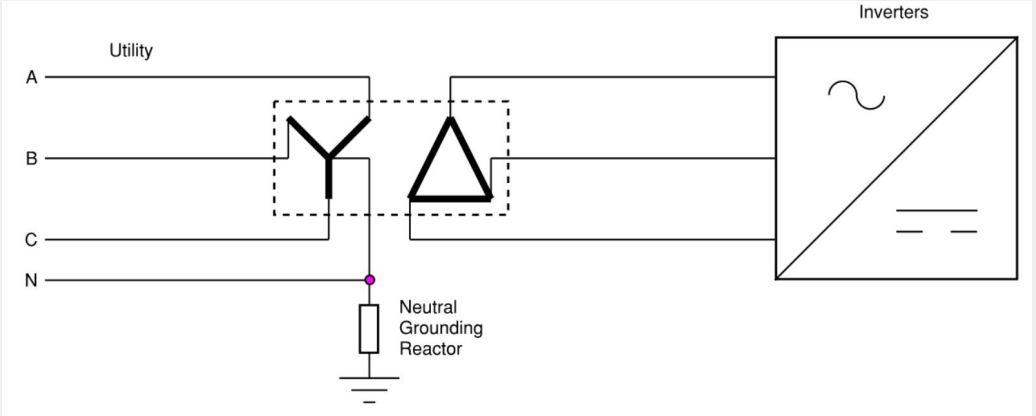
- MA - National Grid (central inverters)
- MA - Eversource [NSTAR] (central inverters)
- NY - National Grid (central inverters)

**Advantages:**

- Effectively Grounding for **ALL** Inverters and/or Energy Storage
- No TOV issues during single phase faults
- Provides ground source for overcurrent detection at PCC

**Current Challenges**

- Lack of wide acceptance for winding configuration
- Desensitization of upstream overcurrent relays
    - Avoided if neutral grounding reactor is adequately sized
- One-Off Utility Requirements



# Grounding Configurations:

*Transformer Configuration - (□ - Yg) or (□ - Y)*

**Utilities where similar configuration is accepted:**

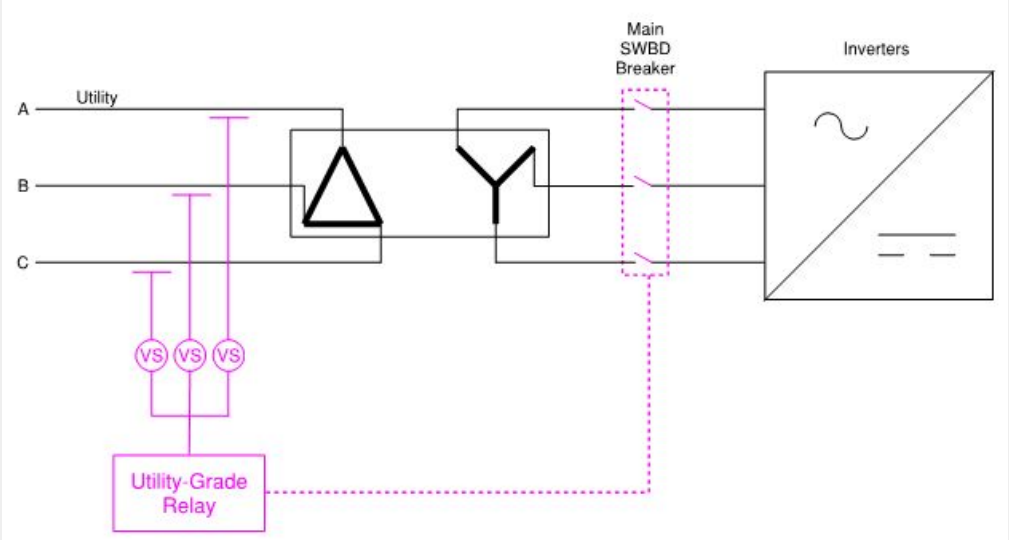
- MA - National Grid (500kW - 1MW)
- MA - Eversource [WMECO] (central inverters)
- IL - ComEd
- IL - Ameren

**Advantages:**

- Applicable for **ALL** Inverters and/or Energy Storage
- No desensitization of upstream overcurrent protection relaying

**Current Challenges**

- Not Effectively Grounded
- Potential for TOV
  - Mitigated with local 3V0 Relay Scheme



# Mitigation Methods

# Mitigation Methods:

*Unique NY Requirements*

**Utilities where unique requirements exist:**

- Central Hudson

**Unique Technical Requirements**

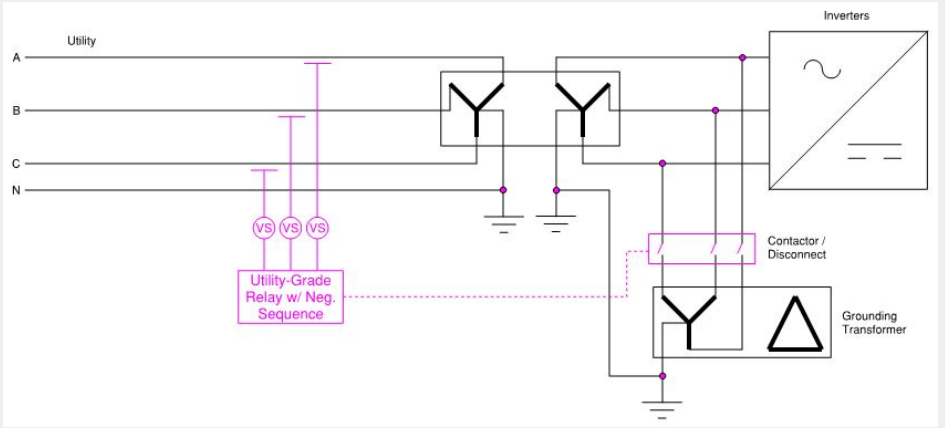
- Voltage reconstruction of single open phase (i.e. backfeeding)
- Ground source disabling while DG site is non operational
- No utility proposed solution exists

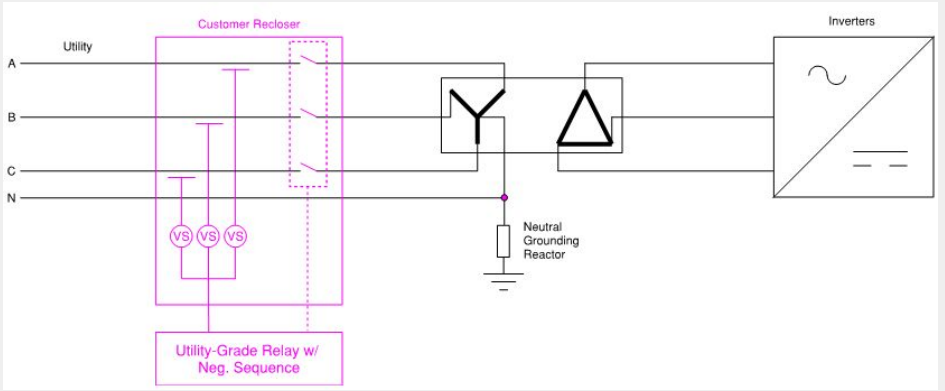
**Proposed Standard Solutions:**

- Single utility grade relay monitoring high side of GSU w/capacitive voltage sensors
- Calculating negative sequence current
- Will directly trip either main switch breaker or contactors

**Proposed Study Methodology**

- < 300kW - No additional mitigation required
- 300kW -1MW - Additional Study Needed
- > 1MW - Mitigation Required



# Developer Requests

# Developer Requests:

## Three-Wire Inverters Permitted by All Utilities

- We have shown the following:
  - Three-wire and four-wire inverters are functionally grounded a do not use their neutral terminal for balancing like synchronous generators
  - The inclusion of a neutral for an inverter is only a detriment to the UL 1741 listing of the inverter
  - Inverters are balanced current-sources which have an open zero-sequence path
    - “The vast majority of three-phase grid-tied inverters are in a phase-to-phase configuration, with no path for zero sequence ac currents. In addition, three-phase inverters are often interconnected to the utility grid by transformers having open zero-sequence paths. Therefore, the generic zero-sequence model for three-phase inverters is an open circuit.” (PES - TR21 or IEEE 62.92.6)
  - The effective grounding concerns of both three-wire and four-wire inverters can be solved by using the correct transformer configuration and ground impedance design.

**Therefore, the developers request that the Joint Utilities agree to allow the installation of three-wire inverters as long as the correct transformer configuration is used to effectively ground the system.**

# Developer Requests:

## Backfeeding Mitigation

- Backfeeding mitigation requirements of some utilities have prevented several projects from interconnecting
  - Current procedure requires developers to introduce mitigation plan before impact study has started which has caused some projects to hold up the queue for months while searching for a solution to the issue
- Efforts to reduce backfeeding risks have been spearheaded by developers without extensive engagement from the utilities
  - Lack of information regarding the issue or previous attempts to mitigate have made it all but impossible to find a solution in the time allotted before the start of the impact study.
  - Some projects which proposed solutions ended up failing to interconnect once construction was completed as their mitigation method did not satisfy the utility disconnect requirements (i.e. disconnection of system ground sources when not generating particularly at night time).

**The solar industry appreciates the opportunity to bring this important issue to the ITWG and looks forward to finding a path forward with the Joint Utilities, DPS, and NYSERDA that will result in creating one or more approved mitigation methods in order to prevent continued delays in the start of CESIRs and in PTO.**

# Conclusions

# Conclusions:

- **The limitations placed on the use of three-wire inverters in some territories drastically limit the available options for inverters and should not be condoned.**
- **The concerns of using three-wire inverters can be addressed and mitigated through the selection and sizing of the interconnection equipment which should be made standard across the utilities.**
- **Assistance with solving interconnection issues such as backfeeding should be given by the JU to increase developer understanding of the utility's concerns and ultimately find an agreed upon solution in a timely manner.**

- **Future Topics In Effective Grounding:**
  - IEEE 62.92.6 (PES - TR21): System Neutral Grounding Considerations for Inverter-Interfaced Distributed Energy Resources

# Sources:


- IEEE 62.92.1: IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems - Part I: Introduction
- IEEE 62.92.6: IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems - Part VI: Distributed Generation
- ENG-TOV-270-01: Neutral Connections and Effective Grounding (Advanced Energy)
- SG125HV Netural, Safety, and Grid Connections (Sungrow)

# Thank You