Impact of Green Power Inverter-Based Distributed Generation on Distribution Systems

Chuck Mozina, Consultant
Beckwith Electric Company

DG History

- DG Started in 1978 PURPA
- Until Recently Mainly Synchronous Generators
- Some Induction Wind Machines
- Today DG Driven by Green Power
- Large Amounts of Inverter Based DGs being Installed

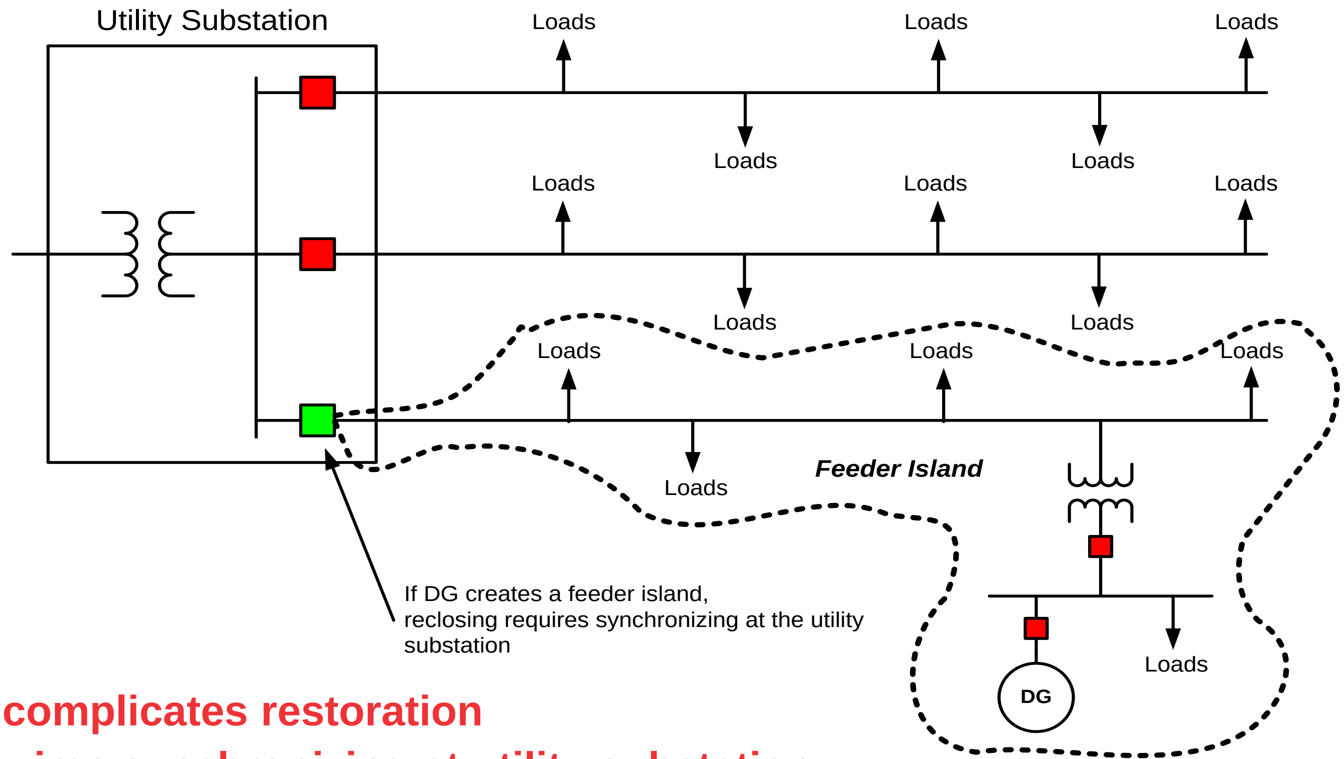
  + Solar

  + Wind

Utility Concerns with DG

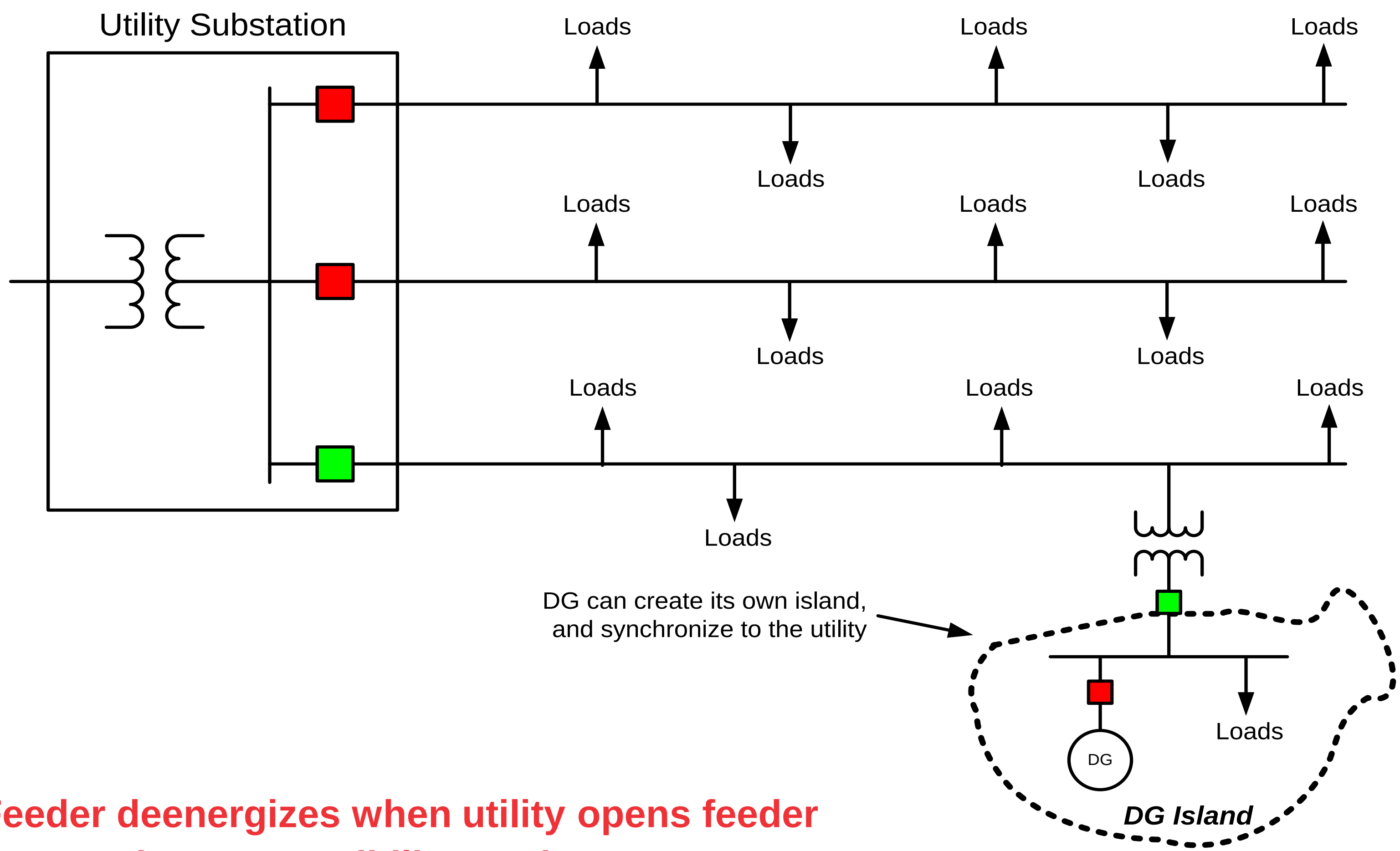
- Loss of Relay System Coordination
- Overvoltages
- Maintaining Adequate Watt/VAr Feeder Voltage Regulation
- Separation Under Islanding Conditions

Islanded Operation of DG with Utility Load is Not Allowed – IEEE 1547



- **Greatly complicates restoration**
  - **Requires synchronizing at utility substation**
  - **Inhibits automatic reclosing**
- **Power quality issue**
  - **DG may not be able to maintain voltage, frequency and harmonics within acceptable levels (load ≠ generation; no harmonic "sink")**

DG Facility Islanding to the Utility is Allowed – IEEE 1547



- Feeder deenergizes when utility opens feeder
- Restoration responsibility on the DG
  - Requires synchronizing to utility
  - Inhibits automatic reclosing

Conventional Synchronous DG Generators' Impact on Distribution Feeders

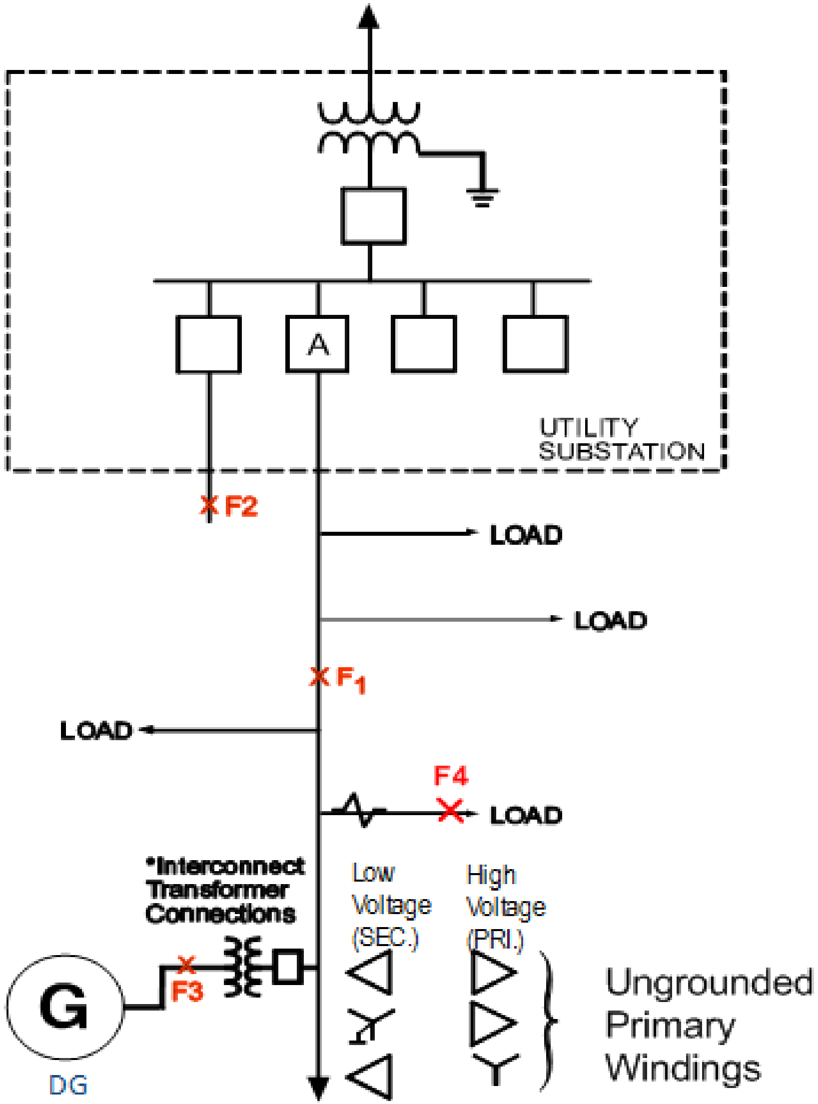
Impact of Interconnection Transformer

- **Ungrounded Primary Transformer Winding**
  - Overvoltage may be caused by DG when ungrounded primary transformer windings are applied (no ground source) and DG backfeeds once utility disconnects
- **Grounded Primary Transformer Winding**
  - Ground fault current contribution caused by DG grounded primary transformer windings during utility faults
  - Source feeder relaying and reclosers responding to secondary ground faults within the DG facility

Ungrounded - Primary Interconnection Transformers

Advantages

- Provide no DG ground fault backfeed for fault at F_1 & F_2
- No ground current from breaker A for a fault at F_3
- No DG ground current –helps Fuse Saving Coordination



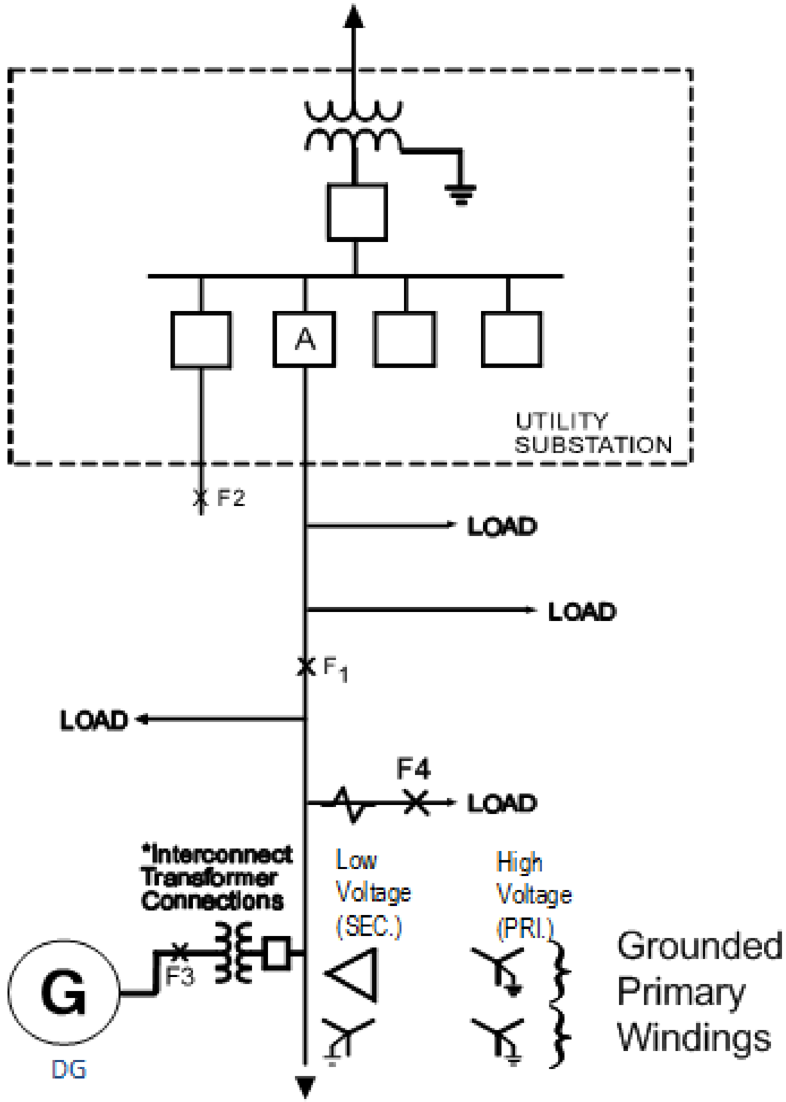
Problems

Can supply feeder circuit from an ungrounded source after substation breaker A trips—causing overvoltage

Grounded – Primary Interconnection Transformers

Advantages

- No ground current from breaker A for faults at F_3 (delta sec. only)
- No overvoltage for ground fault at F_1
- No overvoltage for ground fault at F_2



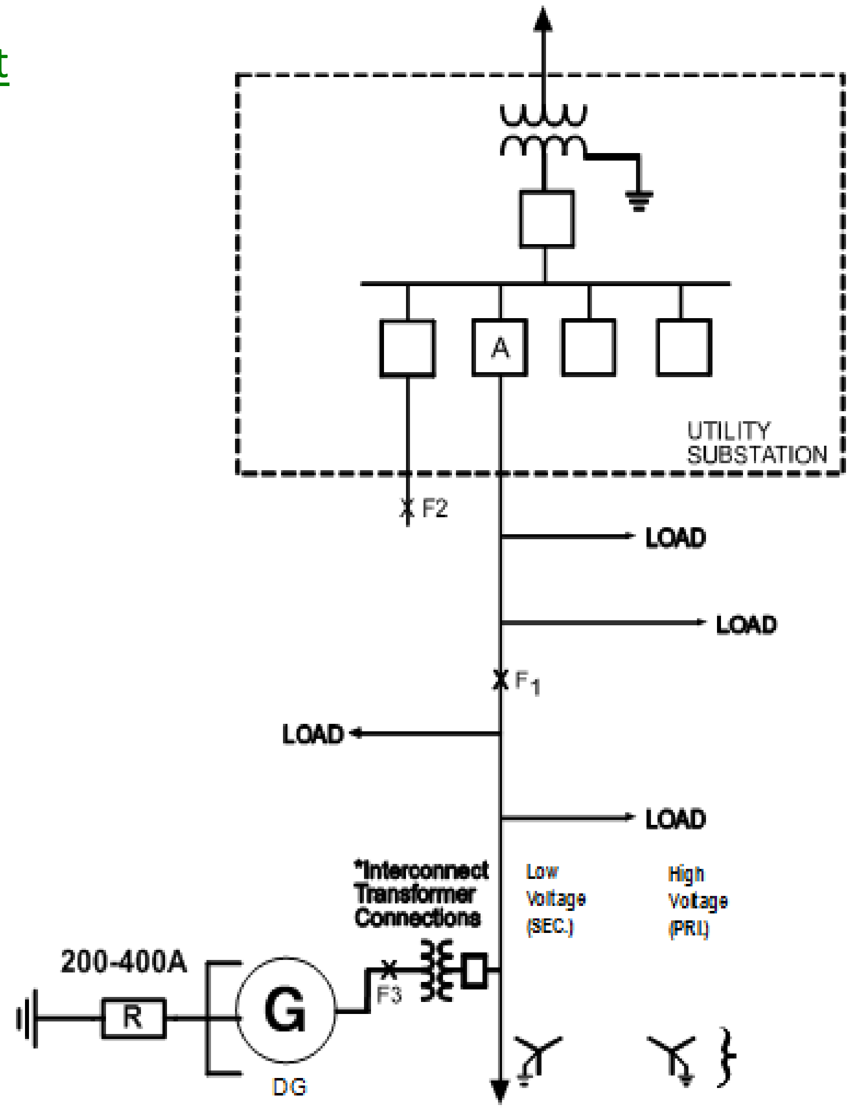
Problems

- Provides an unwanted ground current for supply circuit faults at F_1 and F_2
- Allows source feeder relaying at A to respond to a secondary ground fault at F_3 (Y_{gnd}-Y_{gnd} only)
- Ground current from DG makes fuse saving difficult

More on Wye gnd – Wye gnd Transformers – Are You Really Effectively Grounded?

Effective Grounding Test

- Xo/X1 < 3
- Ro/X1 <1
- Neutral rise on Unfaulted phase less than 140%
- Xo = Zero Sequence Reactance
- X1 = Positive Sequence Reactance
- Ro = Zero Sequence Resistance



Problems

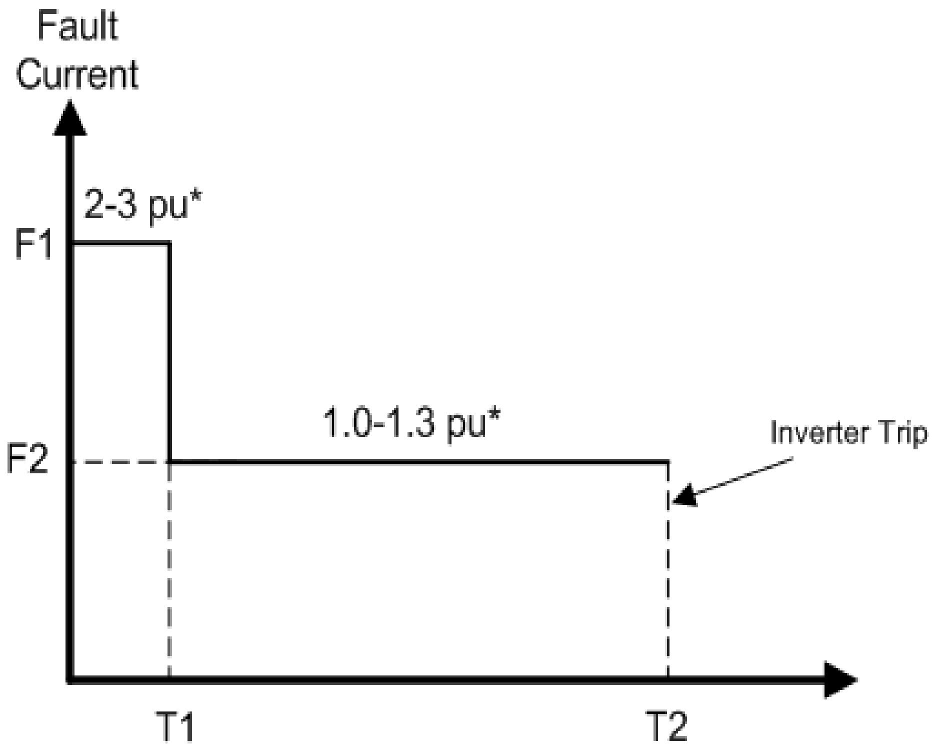
Can supply the feeder circuit from a high-impedance source after substation breaker A trips, causing overvoltage for fault at F1

Inverter-Based DG Generators' Impact on Distribution Feeders

Fault Behavior of Inverter-Based DGs

- Fault Behavior Determined by Controls
- No Generalized DG Models to Predict Fault Behavior
- Two Basic Types Based on Control Scheme:
  - + Voltage Control
  - + Current Control
- Hardware Protection, in Many Cases, Determines Fault and Overvoltage Capabilities

Fault Current Contributions

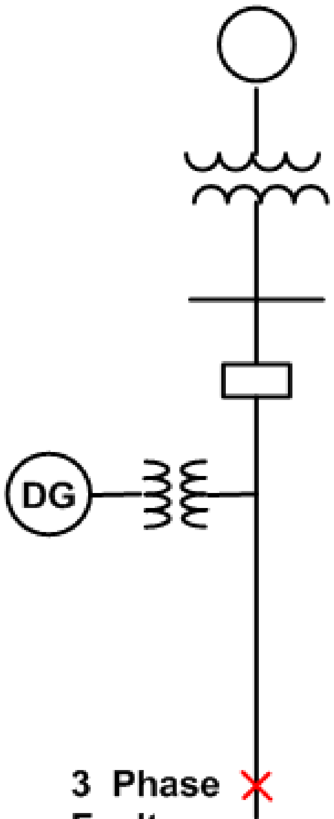


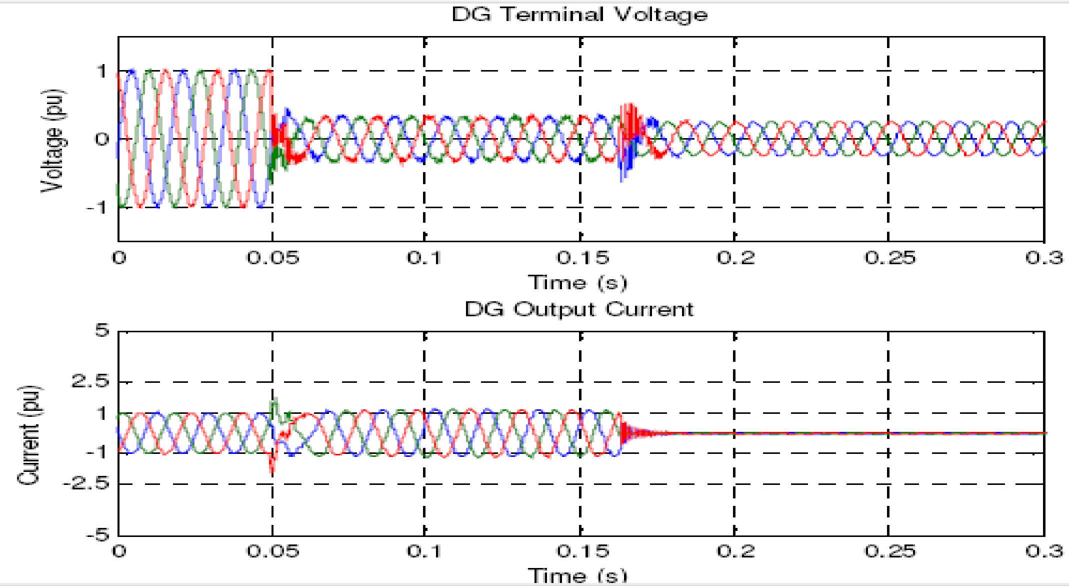
- F1 determined by Impedance between DG and Fault – the smaller the impedance, the higher the fault current. Threshold determined by hardware. Typically 2-3 pu
- T1 depends on control bandwith. Current control – less than ½ cycle. Voltage control – several cycles.
- F2 determined Hardware design. Typically 1.0-1.3 pu
- T2 ends when DG trips or fault is cleared. Future fault–ride through will extend this time. Time can be several seconds. T2 time critical to distribution coordination.

Sequence Current During Unbalanced Faults

- Some Inverter Designs Generate Large Equivalent Negative Sequence Impedance
- Inverters Generally Operate Ungrounded – No Zero Sequence Ground Current
- Interconnection Transformer Grounding Still Plays a Role in Determining Ground Current for Supply Fault.

Fault Current Example:





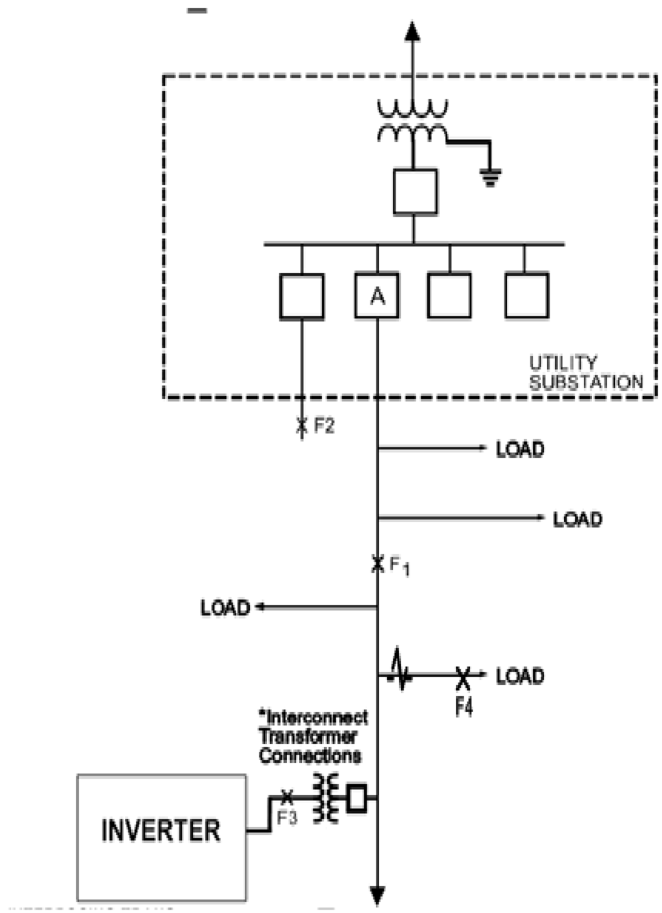
Distance between Substation to Lateral	DG Terminal Voltage[1]	DG Output Current[2]	DG Output Current Contribution (degrees that I lags behind V)	Trip Time (second)
1 Miles	0.14 pu	1.2 pu	102.5	0.12
5 Miles	0.43 pu	1.2 pu	66.0	0.12
10 Miles	0.61 pu	1.2 pu	51.8	1.8
15 Miles	0.72 pu	1.2 pu	42.1	1.8

(1), (2): Voltage and current base is rated voltage and rated current of DG

Coordination Issues:

Advantages

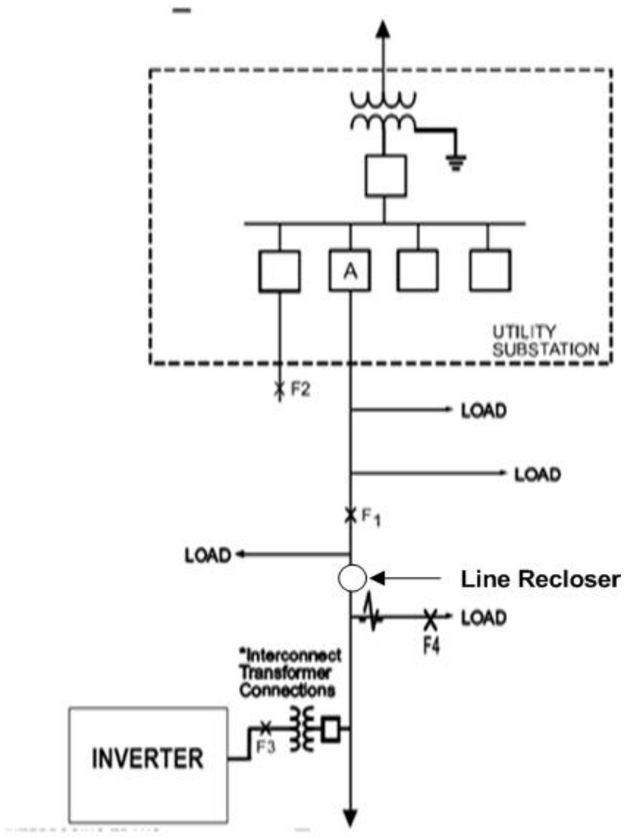
- Less fault current than a synchronous generator
- Makes fuse save easier
- Are there overvoltages due to neutral shift ???
- Inverters are generally ungrounded



Problems

- Provides an unwanted fault current for supply circuit faults at F_1 and F_2
- Allows source feeder relaying at A to respond to a secondary ground fault at F_3 (Y_{gnd}-Y_{gnd} only)
- Ground current duration from DG difficult to determine.

Coordination Issues with Line Reclosers:



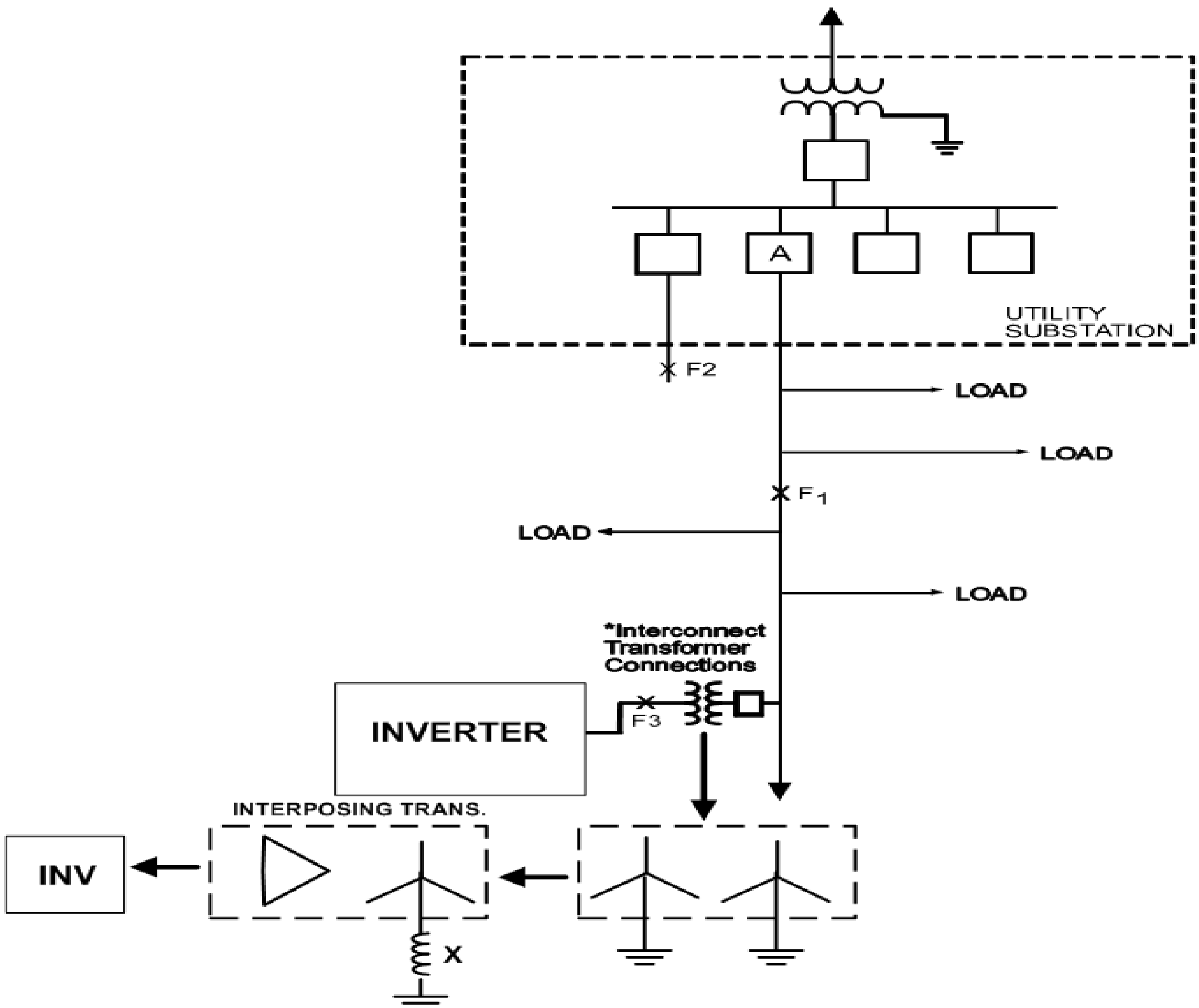
Advantages

- Less fault current than a synchronous generator
- Makes fuse save easier

Problems

- Provides an unwanted fault current for supply circuit faults at F_1 and F_2
- May cause Line Recloser to trip for fault at F_1
- Current duration from DG difficult to determine.

Wye gnd – Wye gnd Transformers –
Are You Really Effectively Grounded? Traditional Utility



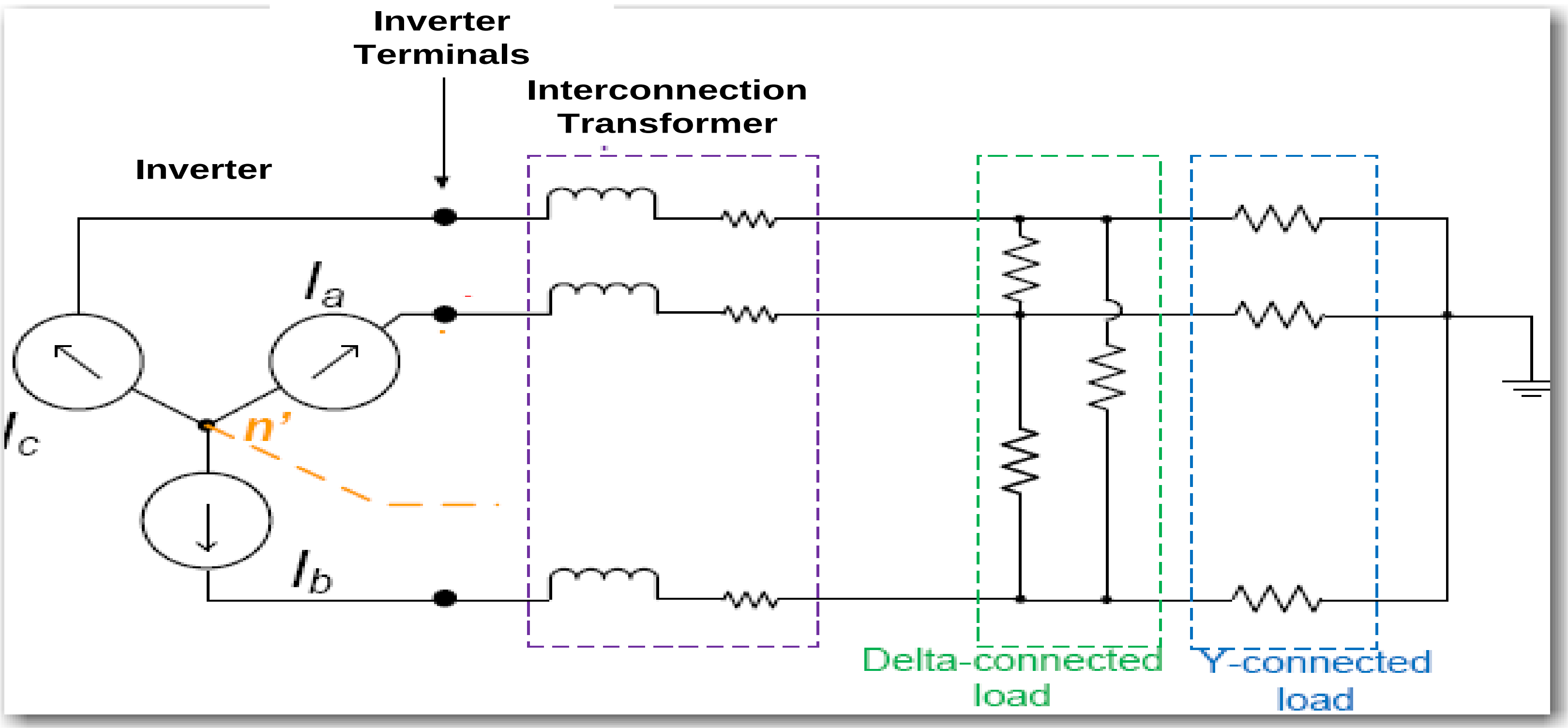
Problems

Can supply the feeder circuit from a high-impedance source after substation breaker A trips, causing overvoltage for fault at F1

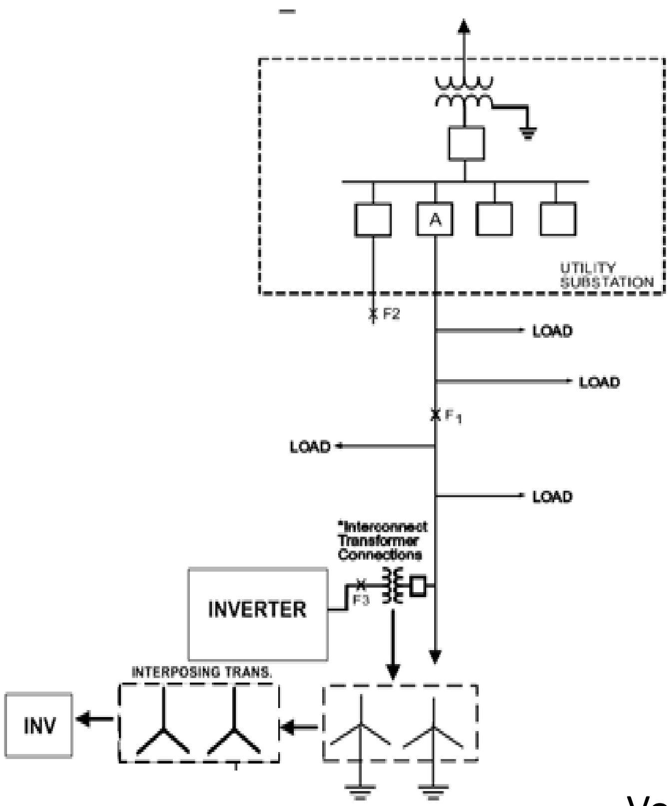
SOLUTION ????

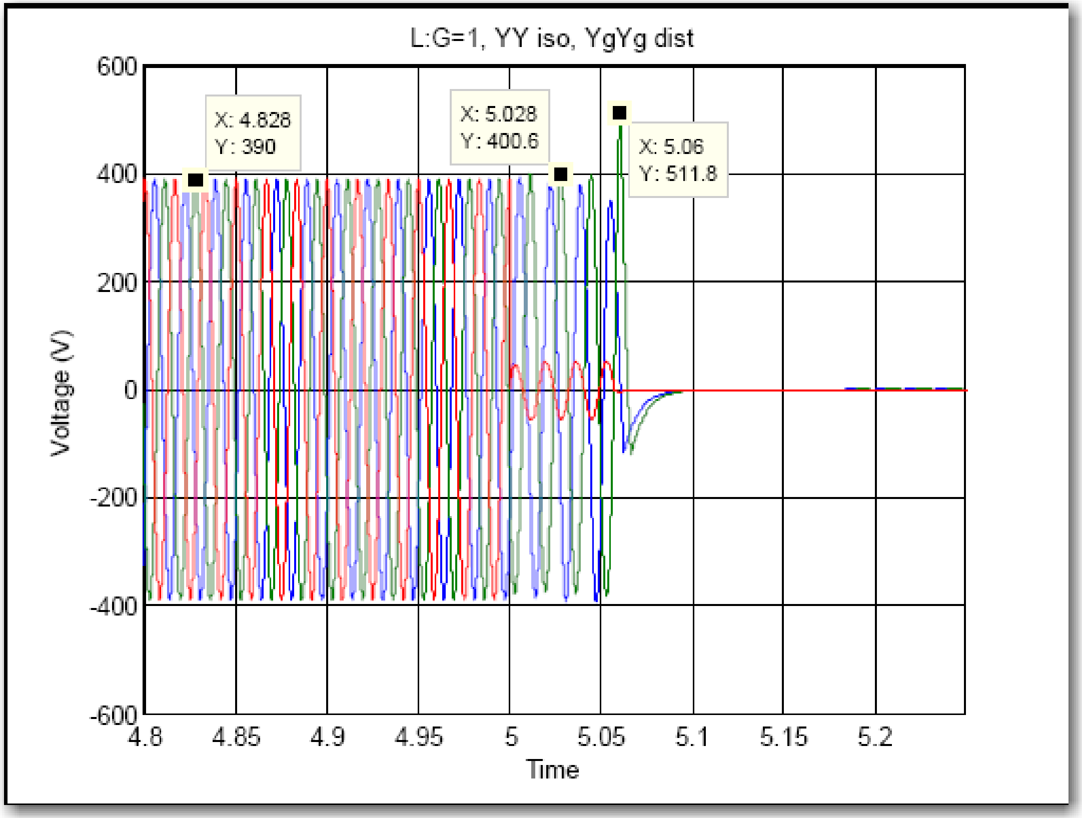
Interposing Transformer can provide a grounded source if Xo/X1 < 3 and Ro/X1 <1.
But is this a good solution?

Overvoltage Potential
Simplified Schematic of Inverter Based DG



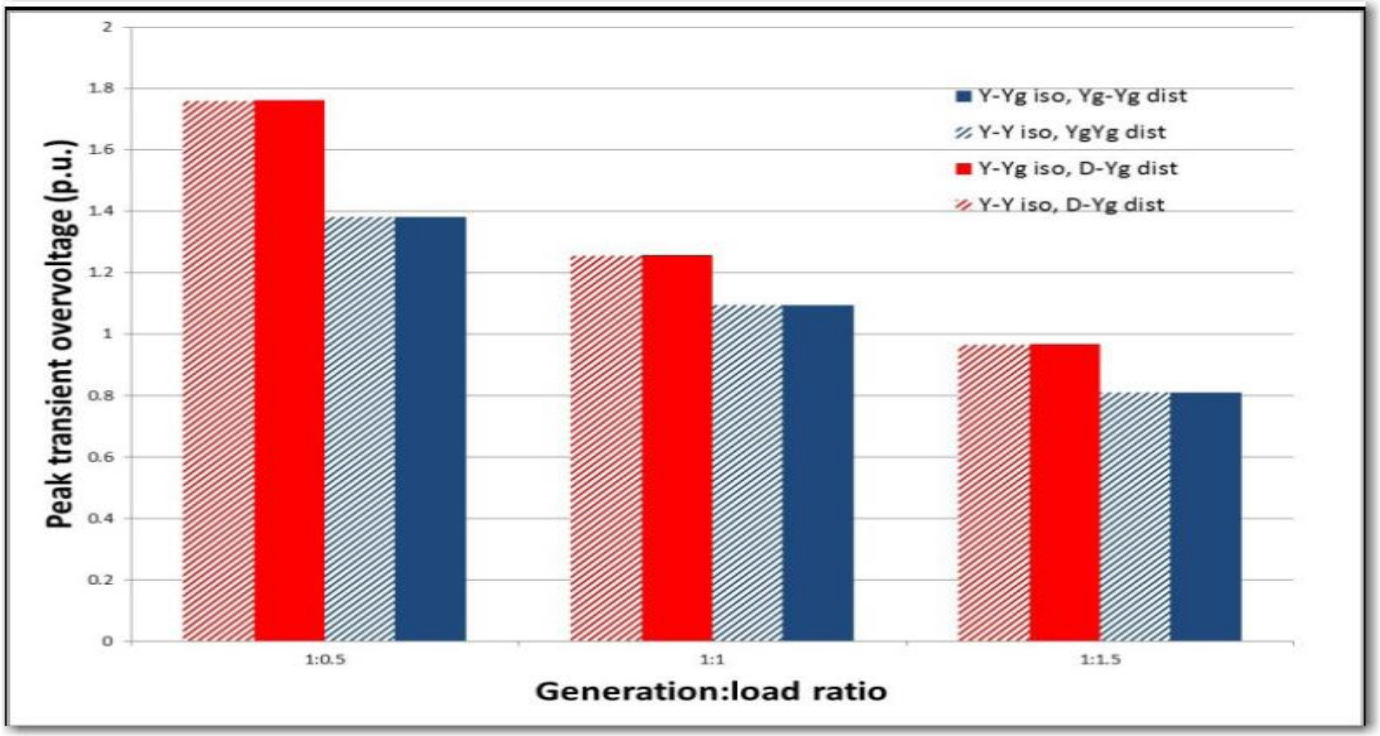
Wye gnd – Wye gnd Main Transformers & Wye –Wye Ungrounded Interposing Trans.





Voltages on the 480 V load bus during an LG fault on the customer side of a YgYg distribution transformer. Generation:load ratio = 1:1; inverter isolation transformer is YY (ungrounded).

Summary of Overvoltages for a Fault on Feeder



Solid columns correspond to grounded inverters (grounded isolation transformers), and the cross-hatched columns correspond to ungrounded inverters. Delta of dist. Transformer is on the primary

IEEE Guidance on Need for External Interconnection Protection

- **Class 1 (< 250Kw)**

  + Rely on Internal Inverter Protection to Disconnect

  + Check if UL 1741 Compliant

  + Generally will trip if load to Generation is Mis-Matched by 10%

  + Time to trip not precisely know

- **Class 2 (250Kw to 1.5 Mw)**

  + Check to see if UL 1741 Compliant

  + Gen./Load < 90% under minimum load conditions

  + Time to trip not precisely know

  + May need External Interconnection Protection

- **Class 3 (1.5 – 10 Mw)**

  + May not be UL 1741 Compliant

  + Gen./Load < 90% under minimum load conditions

  + Time to trip not precisely know

  + Probably needs External Interconnection Protection

Benefits of External Interconnection Protection

.

- Precise Tripping time of Inverter Fault Current Contribution can be Established Making Coordination Easier.
- Automatic Reclosing Time of Substation and Line Reclosers can be Accurately Determined.
- A Precise Reconnect Time After Restoration can be Established.
- Tripping is Independent of Inverter Control
- Changes in Utility Distribution System can be More Easily Accommodated.

Conclusions

- There are Substantial Differences Between Inverter-based and Synchronous DGs that Effect Both Fault Current and Overvoltage.
- Fault Current Behavior is Largely Determined by Inverter Control.
- Inverter-Based DGs Fault Current Magnitude is Limited to approximately 1.3 pu, while Time to Trip Depends on DG Terminal Voltage.
- Effective Grounding of Inverter DGs Location not Needed to Mitigate Overvoltage.
- Interconnection Transformer Ground Still Plays a Role in Determining Overvoltage. Wye-Grounded / Wye-Grounded Appears to be the Best Choice.
- Independent Interconnection Protection which Brackets Voltage & Frequency is Prudent for Larger Inverter-Based DGs.

Impact of Green Power Inverter-Based Distributed Generation on Distribution Systems

Chuck Mozina, Consultant
Beckwith Electric Company

QUESTIONS?