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DG Resources Connected to Distribution Systems

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CRN DG Course

- PSE has developed a 1 ½ day course focusing on DG for CRN
  - IEEE 1547
  - Engineering Studies
  - Inspection & Testing
  - Operations & Maintenance
  - Policies
- Contact NRECA if you would like more details
  - Janet Bowers (703-907-5622 or Janet.bowers@nreca.coop)

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Types of Distributed Generation

Technology	Typical Applications			
	Residential	Commercial	Utility	3rd Party
PV (solar)	X	X	X	X
Wind	X	X	X	X
Hydroelectric	X	X	X	
Combined Heat & Power*	X	X	X	
Fuel Cell*		X	X	X
Microturbines*		X		X
Energy Storage*			X	
Reciprocating Engine				
- Landfill Gas Methane			X	X
- Bio-Digester Methane		X		X
- Diesel		X	X	X
- Natural Gas		X	X	X

* Considered emerging technologies with limited commercial availability

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DG Classifications

- From a utility interconnection standpoint, DG systems can be classified by type of electrical converter (or type of generator that interfaces the system to the distribution system)
  - Synchronous machines
  - Induction machines
  - Inverters and static power converters

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Synchronous Machines

- Produce AC
- Has to be synchronized with the distribution system voltage, frequency and phase angle
- Requires complex controls
- Real power output (watts) controlled by the governor of the prime mover
- Reactive power output (VARs) controlled by level of field excitation
- Controllable power factor
- Significant fault contribution
- Capability for “islanding” to occur

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Induction Machines

- Produce AC
- Basic control systems
- Rotational speed has to be higher than that required for exact synchronism with utility; otherwise, the generator becomes a motor and consumes power
- Reactive power has to be supplied by an external source
- Reduced capability for islanding unless sufficient capacitance is in parallel to provide self-excitation

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Inverters and Static Power Converters

- Convert DC or non-synchronous AC to synchronous AC (DC-to-AC or AC-to-DC-to-AC)
- Provide power conditioning
- Controllable power factor
- Used with PV, wind turbines, fuel cells, battery storage, DC generators
- Less familiarity at the utility level
- Protective functions can be integrated into the inverter
- Limited capability for islanding to occur

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Summary of DG Characteristics

	Inverter	Induction Machine	Synchronous Machine
General Characteristics	Commonly current source-like (strictly voltage regulated, current controlled) in grid-tied mode; voltage source in stand-alone mode Low inertia (capable of very high-speed response)	Inherently current source; can be made to act as a voltage source with external excitation High inertia (relatively slow response)	Voltage source High Inertia
Fault Current Capabilities	Low (typically <1.2 X normal current)	Medium (6 X normal current)	High (10 X normal current)
Power Quality	Total harmonic distortion and DC injection must be controlled; controllable power factor	Low total harmonic distortion; power factor must be corrected	Low total harmonic distortion; controllable power factor

Source: *Connecting to the Grid.* Interstate Renewable Energy Council, 2007.

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The question you have all probably asked yourself at one time…

OK, so we have all this distributed generation that may be interconnecting with our systems. How do we best deal with it?

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Interconnection Standards

Interconnection standards, guidelines and technical requirements should be adopted

- Review NRECA DG Toolkit
- Be aware of any state PUC / PSC requirements
- Take advantage of any templates developed by statewide or regional organizations
- Be sure technical requirements adhere to IEEE 1547
- Be sure to include CEO, engineer, legal counsel, member services and rate design folks in the process

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Typical Interconnection Process

- Application
- Preliminary Review
- Screening Process

Used to determine whether an engineering study is needed

- Engineering Studies
- Study Results and Construction Estimates
- Final Go – No Go Decision
- Final Design Review
- Order Equipment and Construction
- Inspection & Testing

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Engineering Studies

What types of studies are needed?

When do I need to complete one of these?

What is the process?

What data do I need?

What tools are available?

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Engineering Studies

- Comprehensive and complete review may be required to identify adverse system impacts
  - Adverse system impacts means that operational limits of co-op facilities are exceeded with the interconnection of a DG facility, which may compromise safety or reliability
- It is common to divide the review process into several steps
  - Provides stakeholders information at decision points
  - Allows process to be more manageable and efficient

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Preliminary Review & Screening Process

- Purpose is to determine
  - If DG facility qualifies for a “simplified” or “expedited” interconnection (if the interconnection process is divided as such)
  - If engineering studies are required
- Typically, “rules of thumb” are used to determine whether any engineering studies are required

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Certification

- In the past, DG systems tended to be uniquely designed for each installation
- For smaller inverter-based systems (PV and wind in particular), enough progress has been made in recent years to allow for certification of packaged systems
- Certification means that factory testing to certain codes and standards yields plug and play systems that only require limited field testing
  - On-site commissioning
  - Acceptance testing

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Typical Certification Requirements

- Tested by a NRTL to adhere to relative codes and standards (IEEE 1547 and UL 1741 being the most prominent)
- Labeled and publicly listed by a NRTL
- NRTL makes readily available all test standards and procedures
- Verification that the intended use of the equipment falls within the uses tested
- Verification that the generator is compatible with the equipment package and is consistent with the testing

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Certified Equipment

- California and New York maintain lists of certified interconnection equipment
  - http://www.energy.ca.gov/distgen/interconnection/certification.html
  - http://www.dps.state.ny.us/08E1018/SIRDevices.pdf
- Some states have included the equipment on these lists as meeting their requirements for certification

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Engineering Study Review Areas

- Short circuit analysis
- Protection and coordination
- Power flow and voltage drop analysis
- Flicker analysis
- Reliability and System Operation
- Monitoring
- Communications

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Case Study

- Landfill gas generator interconnecting to 12.47/7.2 kV distribution feeder
- Caterpillar 820 kW /1,025 kVA methane-fueled synchronous generator with output at 480V
- Generator protection = Basler relays
- Intertie protection = SEL-351S relay
- System Impact and Facilities Study completed while project was in design phase

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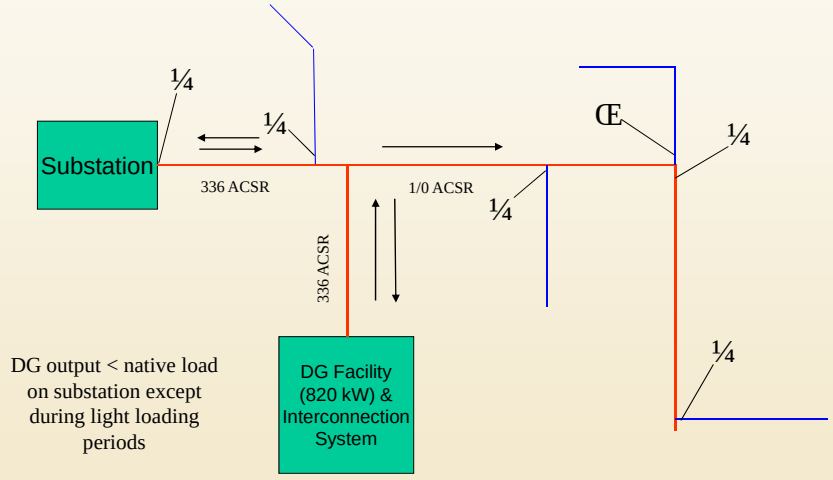
Simplified Circuit Diagram



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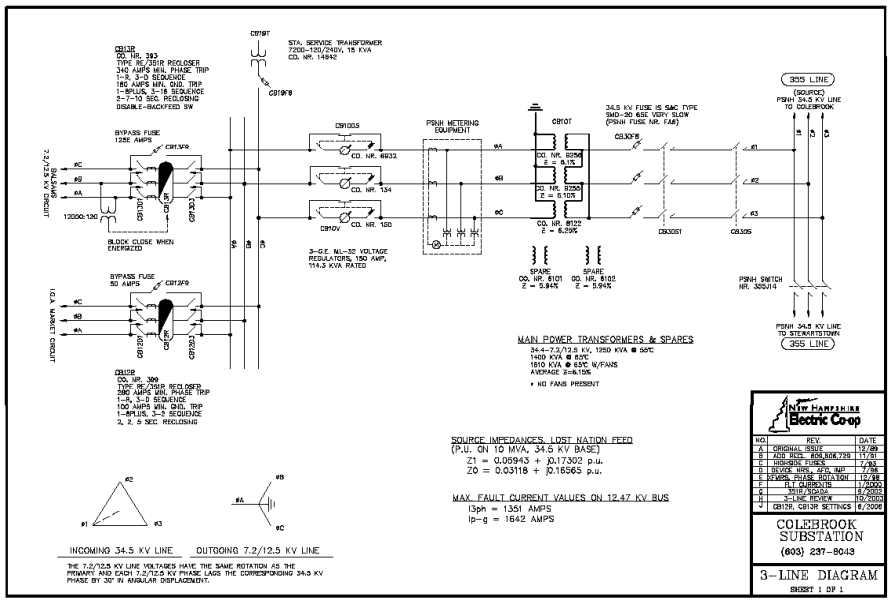

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Transmission Provider Review

- Reverse power flow on to transmission provider's 34.5 kV sub-transmission possible during light loading periods
- Transmission provider review required
  - No thermal or voltage issues found
  - Flicker when DG trips offline may be > 3% (transmission provider standard)
  - Limiting generation operation range to .95 pf lagging to .98 of leading may mitigate flicker concern
  - No additional protection required from their standpoint since DG output does not exceed 30% of min load

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Power Flow and Voltage Drop Analysis

- Milsoft WindMil model used to complete analysis
- 4.8 miles of 336 ACSR installed between co-op substation and DG interconnection
- No thermal or voltage issues from addition of DG
- Voltage regulation
  - Bus regulation present at co-op substation
  - Line drop compensation (LDC) is not being used
  - No changes required to existing bus regulator settings

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Transient Analysis

- Following transmission provider recommendation to limit the operating range of the generator will mitigate flicker concerns on the co-op distribution system as well
- The intended use of the DG facility is for constant operation
- Expected frequency of flicker events is limited
- A larger voltage dip may be tolerated if it does not occur very frequently

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Interconnection Transformer

- 1000 kVA padmount transformer grounded-wye (co-op side) – delta (generator side)
- Transformer connection
  - Allows generation to supply ground fault current to the co-op distribution system (even if the generator is offline) as long as the transformer is connected to the system
  - Mitigates overvoltages on the co-op distribution system during line-to-ground faults

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Step-Up Transformer Impacts

- Primary winding (co-op side)
  - Ungrounded (delta or wye) may cause overvoltages on co-op distribution system for ground faults
    - If distribution feeder load is >> than DG capacity, then this can be avoided
    - Rule of thumb – do not use ungrounded primary winding if minimum feeder load is < 2x the DG capacity
  - Grounded primary allows DG to supply ground current for faults on co-op distribution system
    - Can de-sensitize co-op ground protection schemes
    - Can interfere with fuse saving schemes

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Step-Up Transformer Impacts

- Secondary winding (DG side)
  - Delta - If the primary is grounded-wye, ground current will be supplied as long as the transformer is connected, even if the DG is offline
  - Grounded-wye – allows ground fault contribution from the co-op distribution system for faults on the DG side of the transformer

Tip: Both Basler Electric Company and Beckwith Electric Company have a number of very good papers on this topic

- http://www.basler.com/html/dwntech.htm
- http://www.beckwithelectric.com/infoctr/index.htm

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Interconnection Protection

- Proposed DG relaying consistent with co-op technical requirements
  - Utility grade relays
  - Overcurrent relaying (50/51, 50/51G, 50/51N)
  - Voltage controlled overcurrent relaying (51V)
  - Over-voltage relay (59) / Under-voltage relay (27)
  - Over/Under Frequency relays (81O/U)
  - Synchronism check relay (25)
  - Lockout relay (86)

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Interconnection Protection

- Co-op three-phase recloser recommended
  - Provides sensitive ground fault protection
  - Provides backup protection (under co-op control)
  - Integration into a Direct Transfer Trip (DTT) scheme
    - Islanding possible due to possibility of generator output matching load on co-op feeder
    - DTT scheme involves co-op feeder recloser at substation sending a trip command to this recloser when abnormal system conditions are detected
  - Allows for interconnection transformer to be disconnected from the system

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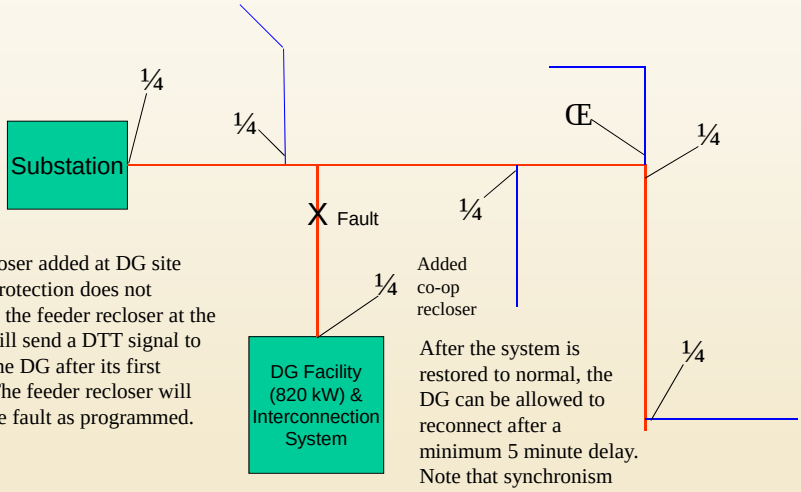
Fault in First Protection Zone



If co-op recloser added at DG site and/or DG protection does not operate first, the feeder recloser at the substation will send a DTT signal to disconnect the DG after its first operation. The feeder recloser will then clear the fault as programmed.

After the system is restored to normal, the DG can be allowed to reconnect after a minimum 5 minute delay. Note that synchronism occurs at the generator paralleling switchgear.

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Distribution System Protection Scheme Impacts

1. Increased available fault current resulting in protection device ratings being exceeded or mis-coordination occurring
   - One device found where rating was exceeded due to DG

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Distribution System Protection Scheme Impacts

2. Reduced ground and phase overcurrent protection sensitivity
   - Feeder recloser at substation ground pickup required to be lowered

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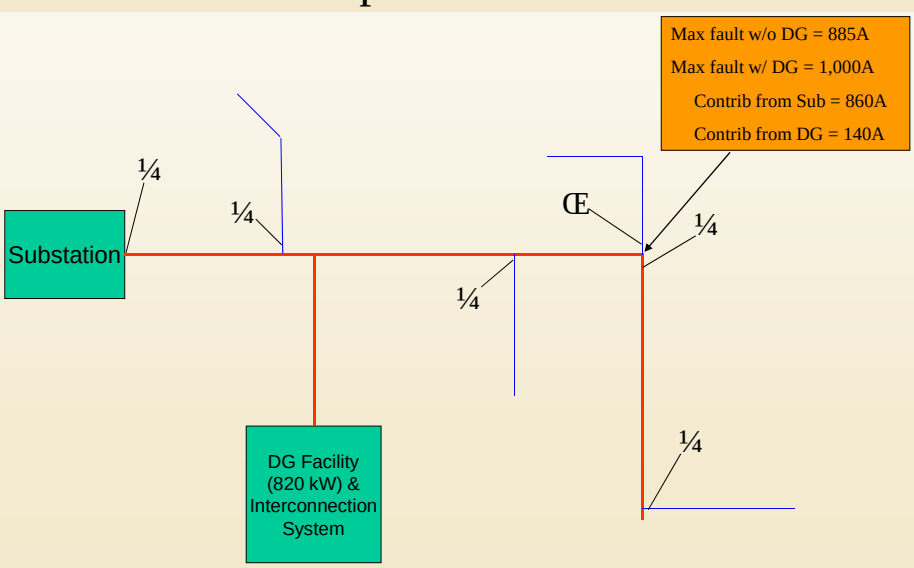
Protection Impacts – Maximum Fault



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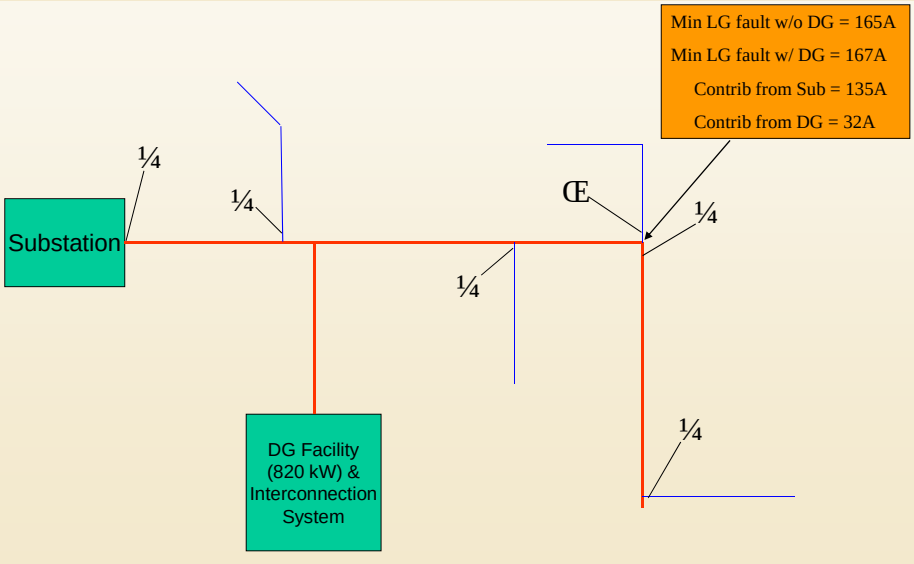
Protection Impacts – Minimum Fault



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Distribution System Protection Scheme Impacts

3. Interference with fuse saving schemes
   - Fuse saving scheme attempts to keep fuses from blowing during temporary faults by allowing upline recloser to operate on fast operations first
   - Reduction in fault current from substation, coupled with overall increased fault current at fault location due to DG can interfere with these schemes

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Distribution System Protection Scheme Impacts

4. Reverse power flow
   - The only existing protection device that might see reverse power flow is the feeder recloser installed at the substation during times when the DG output is > load on the feeder
   - Directional overcurrent protection recommended with the feeder recloser such that the recloser only operates for faults on the DG feeder
   - Fault flow from DG on to other feeders out of the co-op substation will be limited

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Distribution System Protection Scheme Impacts

5. Out-of-synch reclosing
   - The possibility of out-of-synch reclosing exists with the feeder recloser installed at the substation
   - A PT is installed on the load side of this recloser and the existing SEL-351R relay is programmed to block reclosing if voltage is present

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Once it has been determined what is required to safely interconnect a specific DG facility to your system, then what?

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Inspection and Testing

Inspection and testing of DG equipment and its associated interconnection system is important for safety and system reliability. Applicable standards and codes should be referenced when developing or adopting procedures.

- IEEE 1547
- IEEE 1547.1
- UL 1741
- ANSI
- NEC
- NESC

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Commissioning Tests - Before Energizing

Prior to paralleling the DG facility with the distribution system, an installation inspection and number of commissioning tests should be considered.

- Grounding
- Instrument Transformers
- Breaker/Switches
- Relay
- Trip Check
- Remote Control
- Phase
- Synchronism

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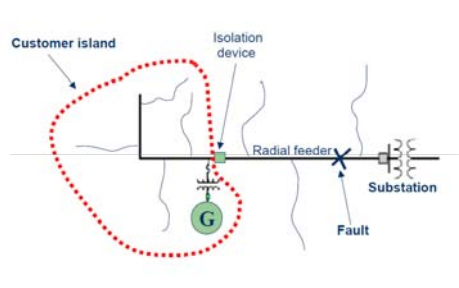
Commissioning Tests – While in Service

Additional testing can be performed after the DG unit is in service and the Local EPS and Area EPS are parallel.

Anti-Islanding Test

This test should demonstrate that the Local EPS or DG facility will cease to energize or isolate itself from the Area EPS when the utility source is lost.



*Source: IEEE P1527.2/D11

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Let's turn our focus to Inverters

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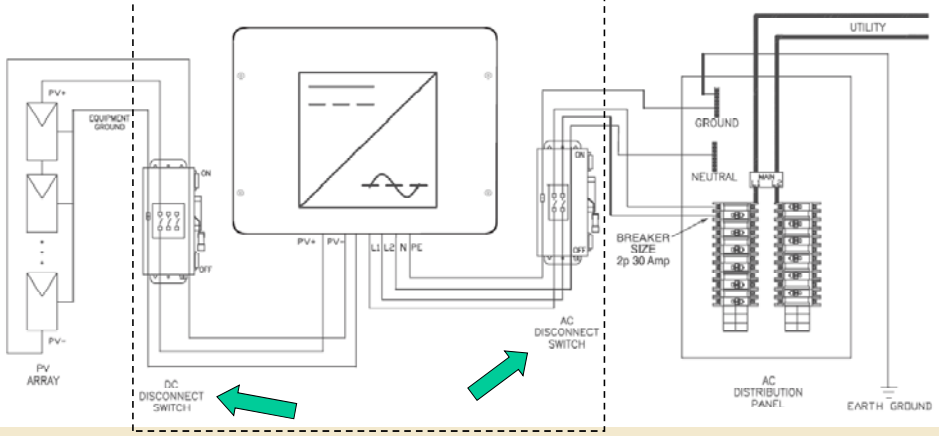
Typical Inverter Installation

Some inverters integrate the DC and AC disconnects into one package



Source: SMA Solar Technology

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External Disconnect Switch

- The National Electric Code (NEC) requires a disconnecting means in a "readily accessible location" be installed
  - Readily accessible to whom?
  - Should you also require a disconnect be installed?
  - If so, who pays for this?
- Your Interconnection Standards and Technical Requirements should address these questions
  - Be sure to review any state requirements

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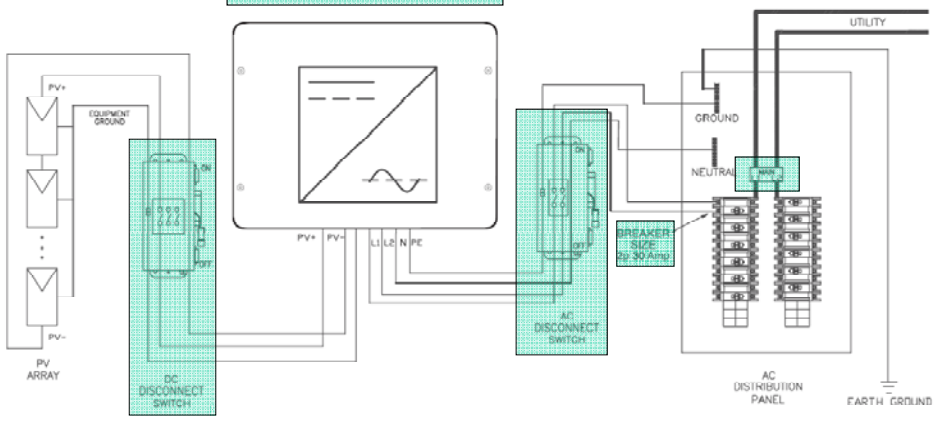
Typical Inverter Installation Means of Disconnecting

- Inverter AC/DC breakers
- Inverter relay (automatic)



Source: SMA Solar Technology

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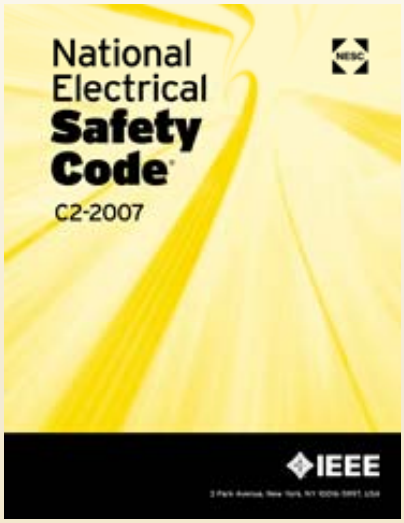
NESC Requirements for De-energized Work



- Section 444 of the NESC details requirements
- Isolate - operate switches, disconnects and lockout / tag
- Test for voltage
- Install protective grounds on each side of the work location

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Conditions Required for an Inverter to Re-Energize a De-Energized Line

1. Inverter fails to disconnect automatically and continues exporting power without the necessary external voltage source present
2. Anti-islanding, voltage and frequency protection fail
3. Output of the inverter ~ matches the connected load such that overcurrent protection (fuse) does not operate

Even if the above were to occur, the requirement to test and ground the line before working on it should protect the line worker

Things We Hope You Take Away…

One or more engineering studies may be required to determine any adverse system impacts

- Preliminary review and screening process identifies when studies are required
- Small inverter-based systems certified to meet UL 1741 and IEEE 1547 typically do not require an engineering study
- For interconnections requiring an engineering study, there are a number of review items that may need to be studied

Things We Hope You Take Away…

Inspection & Testing of DG systems is important for safety and reliability

- Verify that your technical requirements are being met
- Co-op may need to complete certain commissioning tests to verify correct operation of anti-islanding protection, direct transfer trip schemes, etc.

Thank You!

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