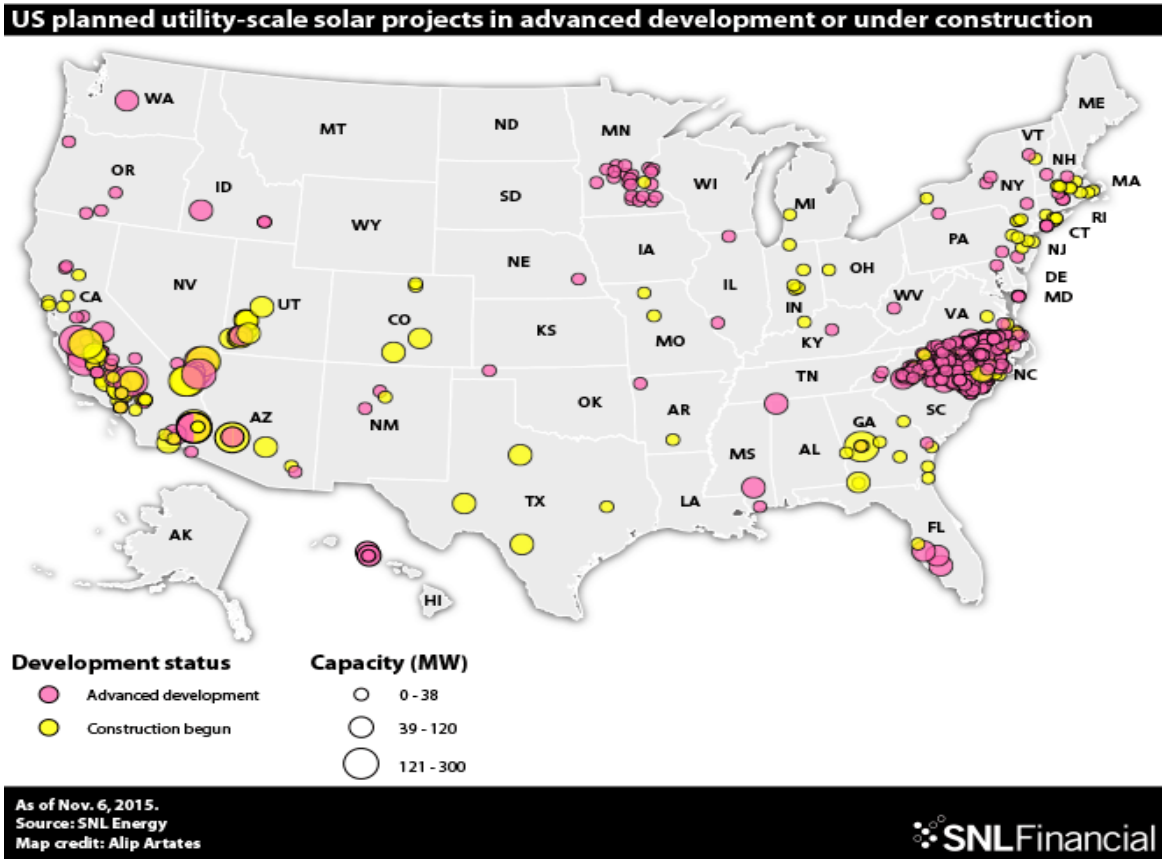

IEEE STANDARDS ASSOCIATION
IEEE
Solar Farms: design & construction
Impacts to utility distribution systems
John W. Gajda, P.E.
Duke Energy
Manager, DER Operations Support
NESC

Agenda

- North Carolina's unique situation, which is coming to a state near you
- Typical solar farm characteristics
- Recent solar farm experiences, investigations, and solutions
- Where do we go from here?

North Carolina: 2nd in nation in solar capacity additions



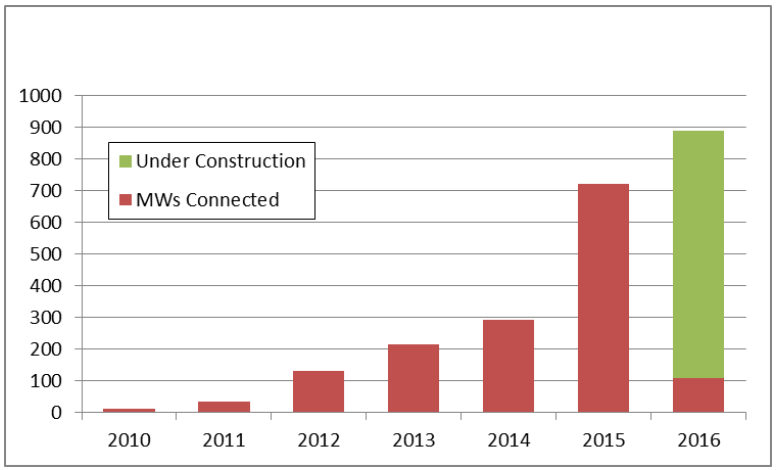
Interconnection Queue: Duke & Progress in North Carolina

	Cancelled	Connected	Open	Under Construction	Grand Total
DEC	1,019	477	624	149	2,269
DEP	5,618	1,126	3,929	631	11,304
Grand Total	**6,637**	**1,604**	**4,552**	**780**	**13,573**

As of June 30, 2016, in NC, Duke Energy:

- has connected over 1,600 MW of solar generation
- received requests for over 13,000 MW of interconnections
- has 780 MWs of 3rd party projects under construction
- is constructing facilities and system upgrades approaching $400,000 per project, averaging six months to complete.

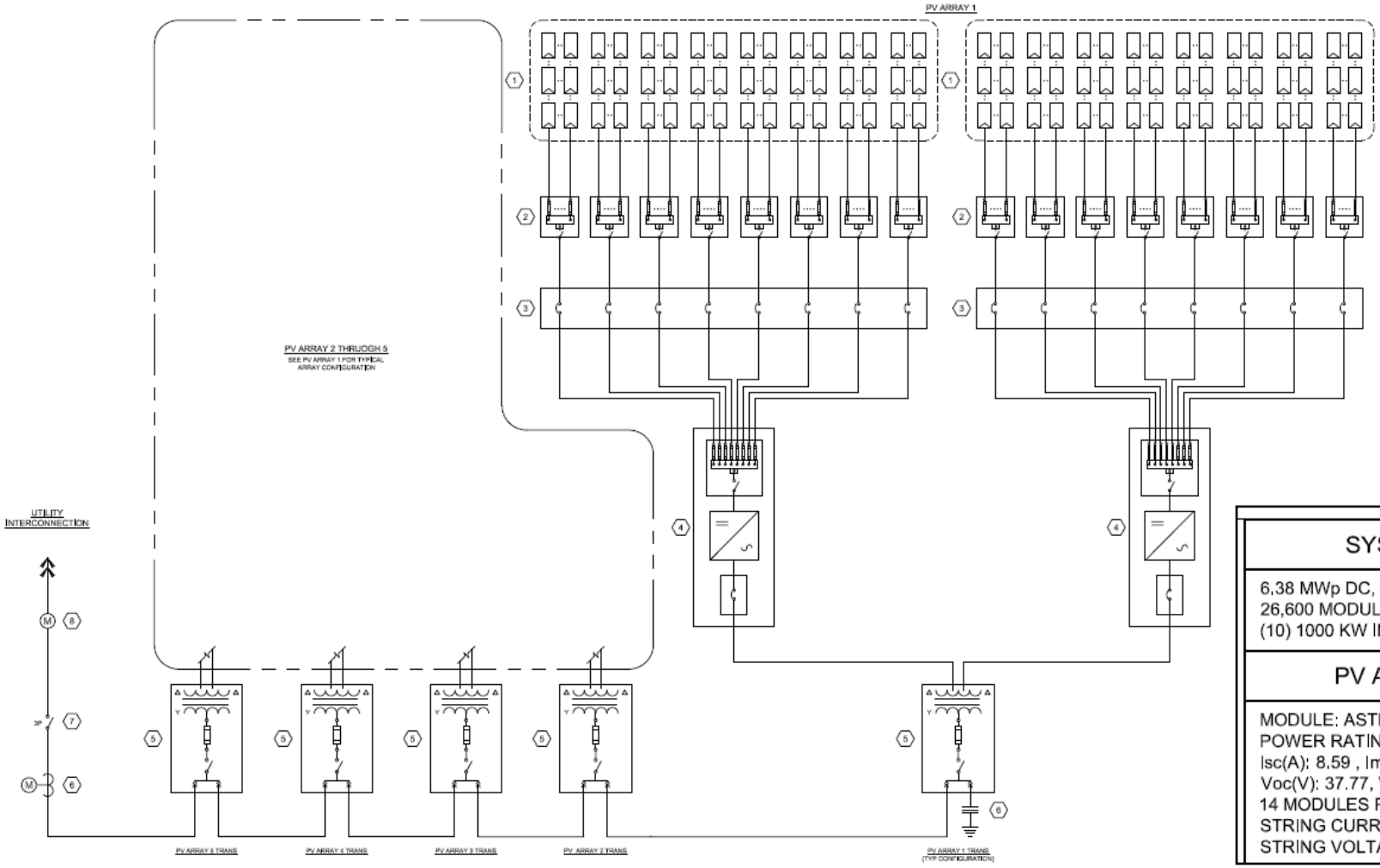
Interconnected MWs



Interconnection Cost ($ in Millions)

Typical solar farm construction on distribution in the Carolinas

- **Characteristics**
  - Primary voltage (12 kV, 23 kV, etc.) at the POI/PCC
  - Range from 1 MW to 20 MW
  - In NC, 5 MW is a popular size
  - 8 acres to over 100 acres
  - Utility overhead facilities
  - Solar farm overhead and underground facilities (primary voltage)
  - Solar farm transformers (pad mount), inverters, panels

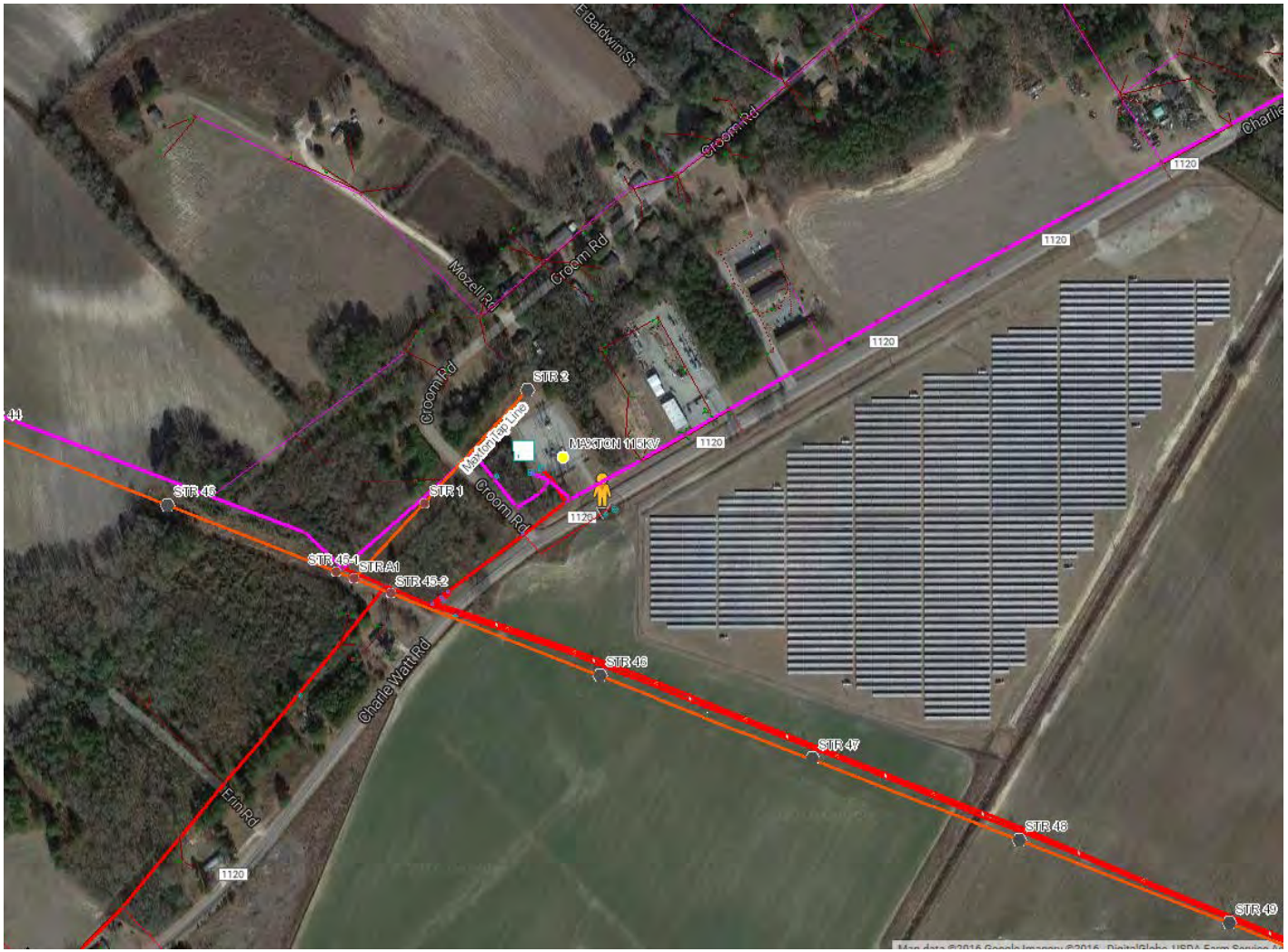


5 MW solar farm
near Maxton, NC

SYSTEM INFORMATION
6,38 MWp DC, 4,975 MW AC 26,600 MODULES (10) 1000 KW INVERTERS
PV ARRAY INFORMATION
MODULE: ASTRONERGY 6610P POWER RATING: 240Wp Isc(A): 8,59 , Imp(A): 8,13 Voc(V): 37.77, Vmp(V): 29.54 14 MODULES PER STRING STRING CURRENT: 8,13A Imp, 8,59A Isc STRING VOLTAGE: 413.56V Vmp, 528.78V Voc

5 MW solar farm
near Maxton, NC

~2000’



NESC

5 MW solar farm
near Maxton, NC

Interconnection at 22.86 KV

NESC

5 MW solar farm near Maxton, NC

POI/PCC

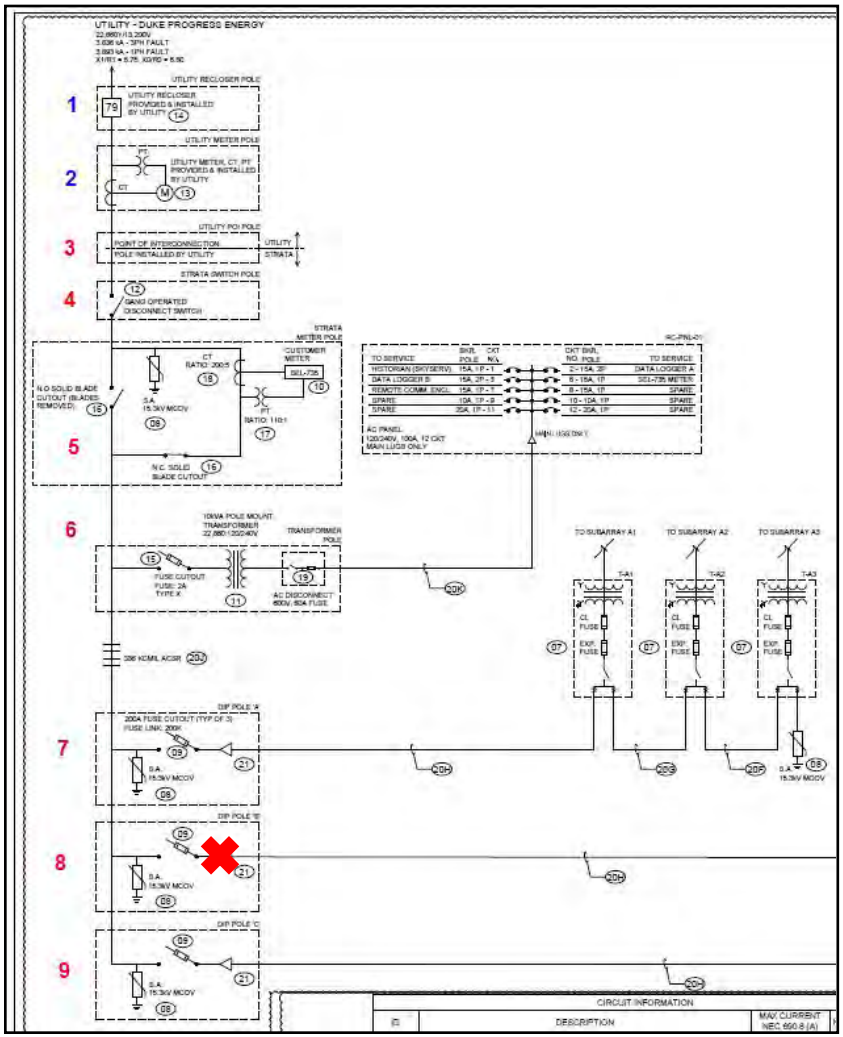
5 MW solar farm near Maxton, NC

- 22.86 kV
- 12 poles
- 360’ utility OHD
- 1500’ solar farm OHD
- Significant underground cable

Another example:

20 MW solar farm
near Maxton, NC

22.86 kV
9 poles

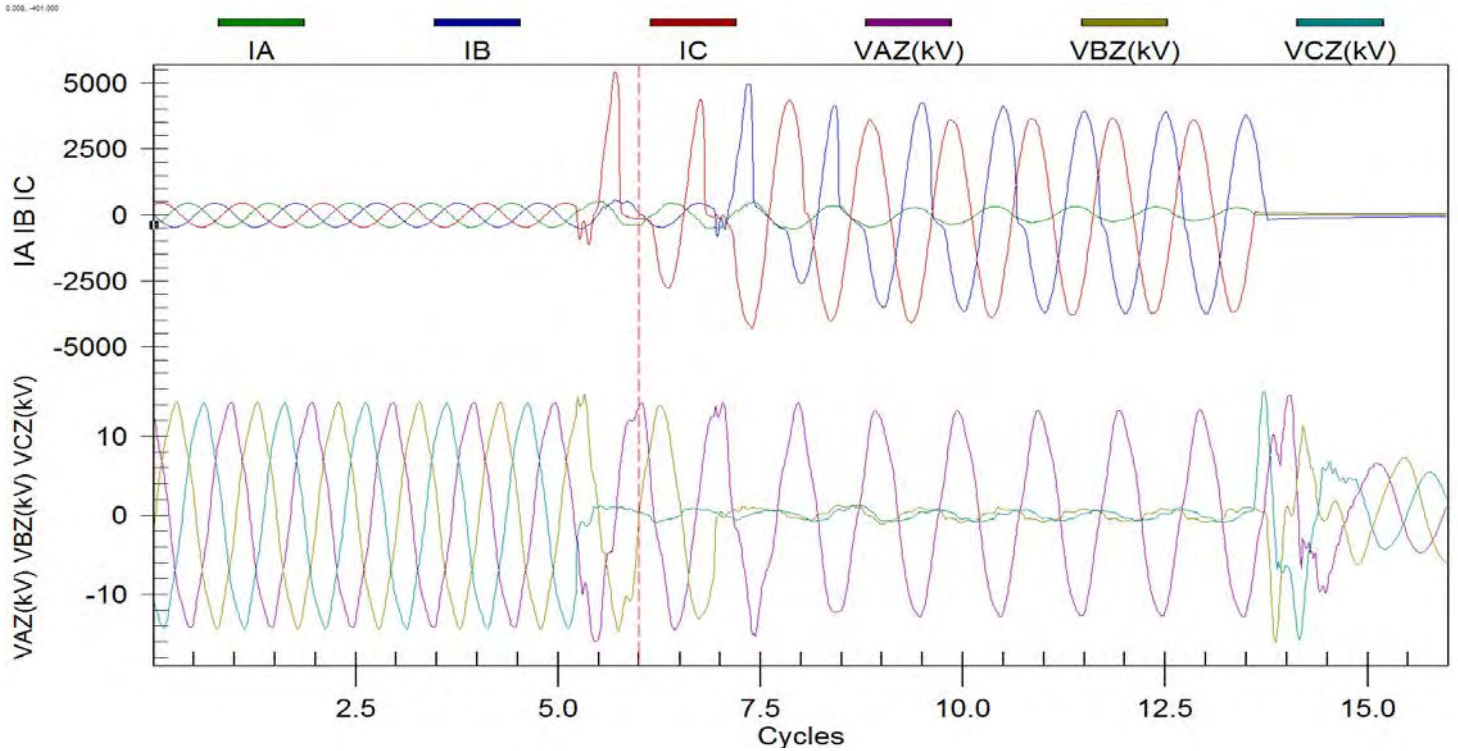


Another example:

20 MW solar farm
near Maxton, NC

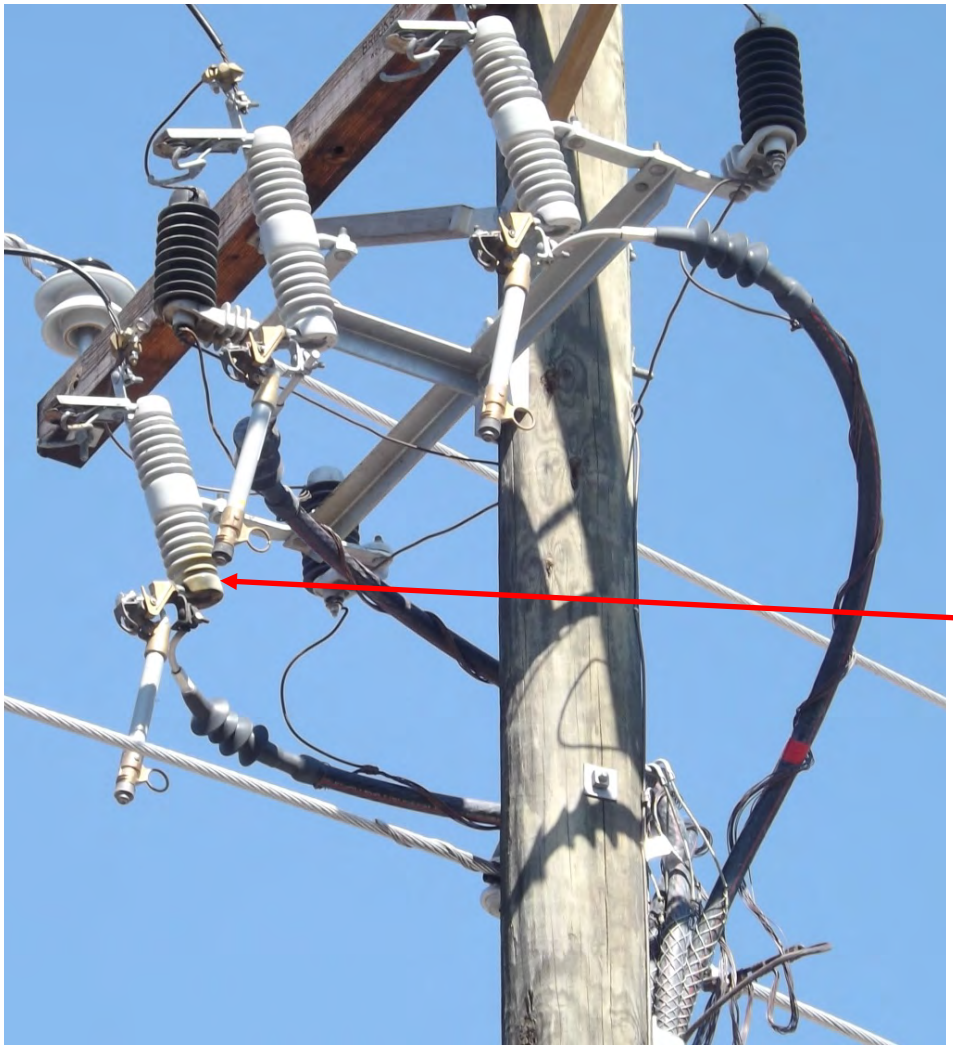
22.86 kV
9 poles

Fault event at solar farm causes customer disruption



Industrial customer on adjacent feeder suffers multiple process disruptions, twice over several weeks

Caused by fault events at 20 MW solar farm



20 MW solar farm site inspection, after second occurrence

dip pole "B" (7th pole)

fault evidence

20 MW solar farm, at dip pole "B":

- C (left) phase fault, developed into phase-to-phase fault
- occurred twice in 15 days

Primary issues identified:

- clearances at stress cones
- terminations

A looming issue?

- **This experience raised awareness of MV construction at solar farms**
  - Exposure:
    - >200 solar farms (≥ 1 MW) in Duke Energy Progress
    - Average size = 4.4 MW
    - Total = 926 MW

- Duke then initiated "investigative inspections" of 8 sites
  - results mixed, but not reassuring

No lightning arresters on any of the 3 dip poles

NESC

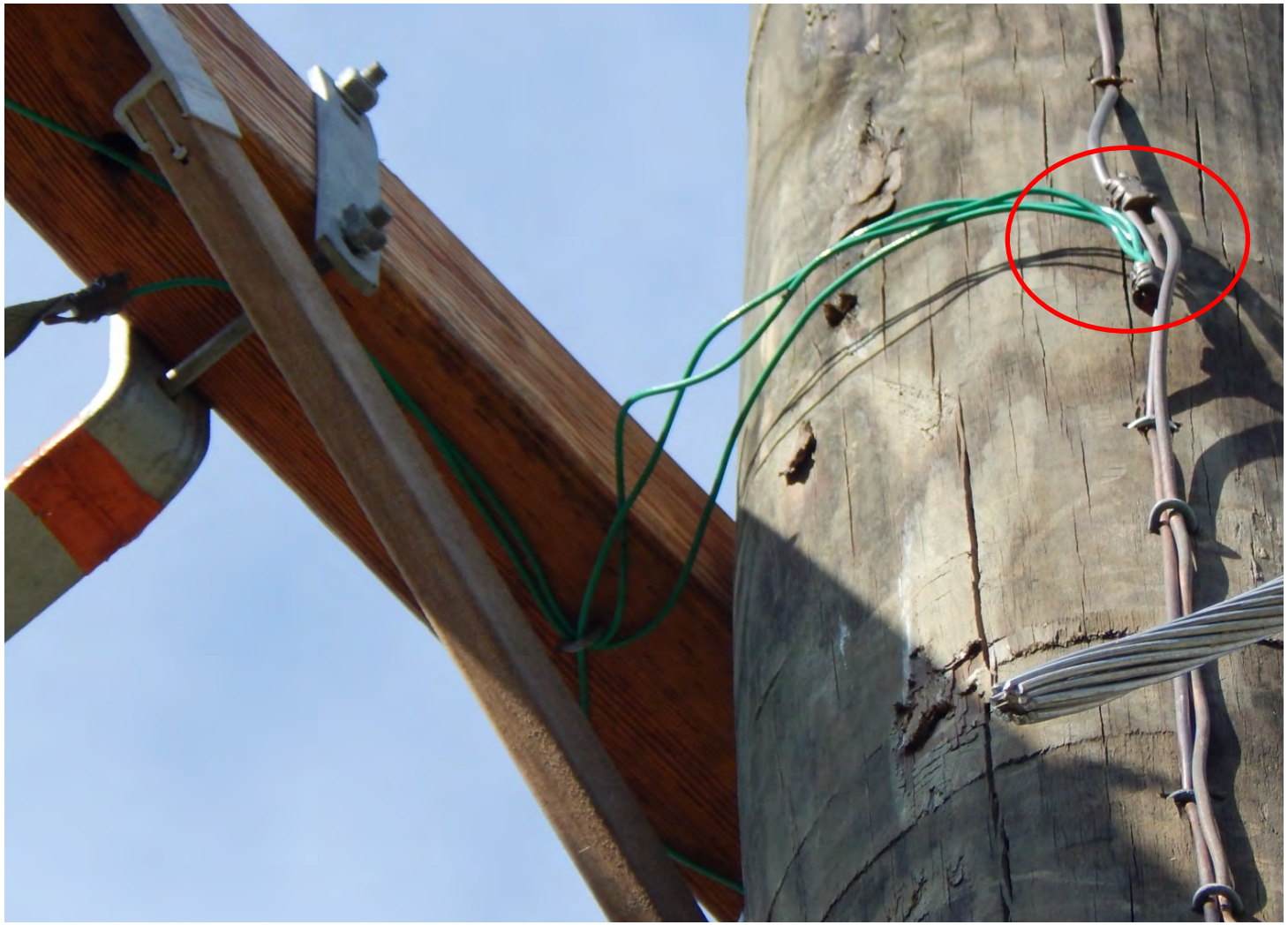
At one site, none of the connections were greased

Lockwashers?

Terminator installed incorrectly.

Reverse dip through wetlands. No arrester protection for terminations.

Messenger wire for fiber is not bonded at all 3 poles (possible induced voltage).



Underground primary cable neutral bonded to very small wire. Weak link.

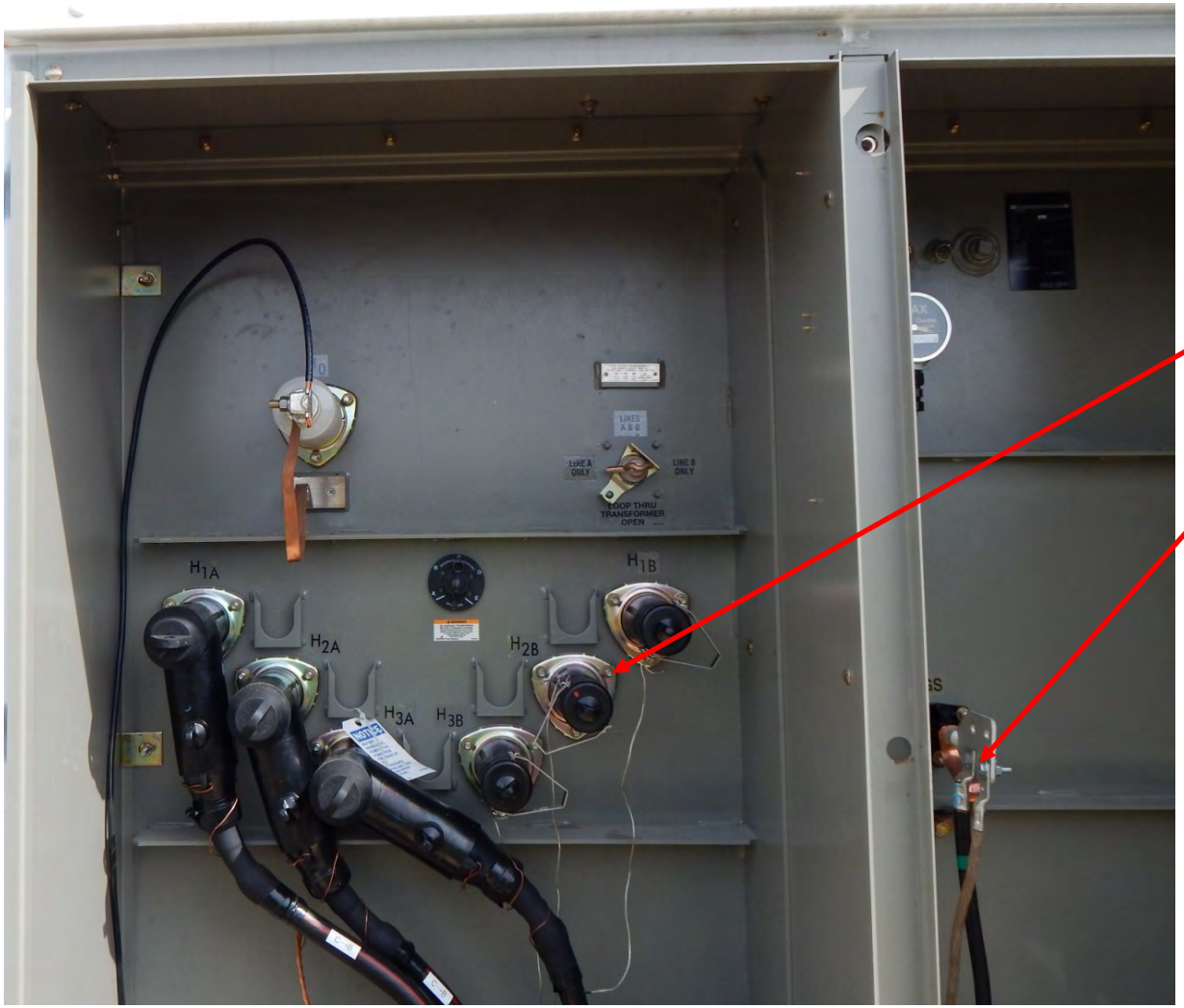
Switch is grounded with separate ground.
Pole ground and switch ground should be commonly bonded.

Metal base of switch extends half way over deadend insulator.

Extension link needed.

12.7kV MCOV rating on arrester

(system here is 22.86 kV/13.2 kV)

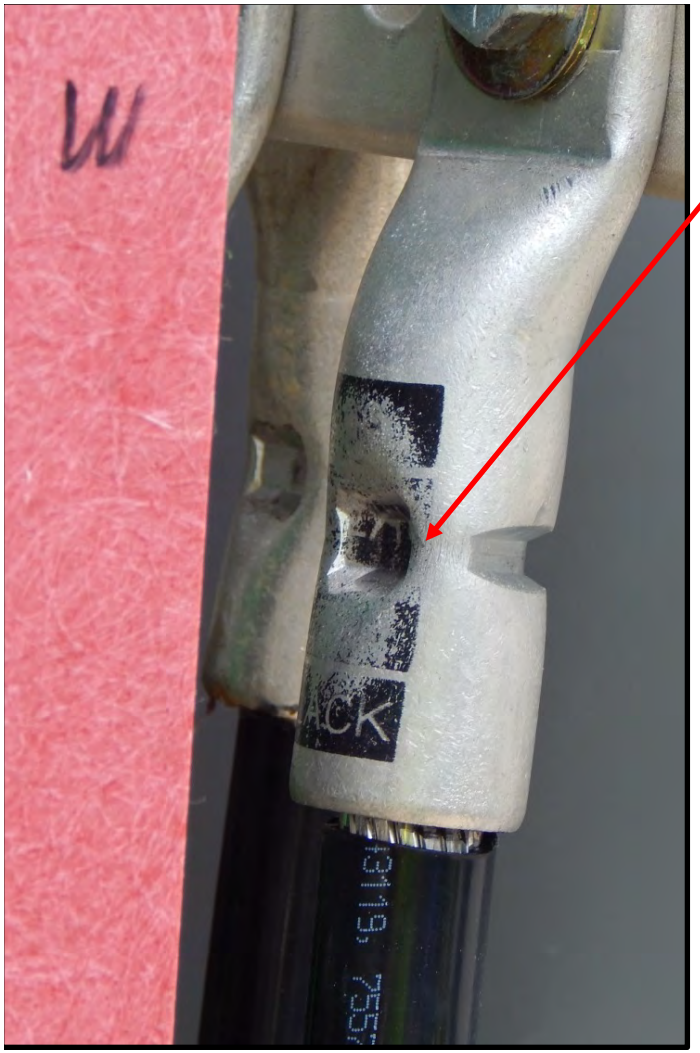


Deadend caps installed with no arresters.

Flat to flat connections ungreased.

NESC

H0 bushing ground strap installed, but no connection to ground bus in transformer.



Only 1 crimp on every connector.

Manufacture requires 4 compressions.

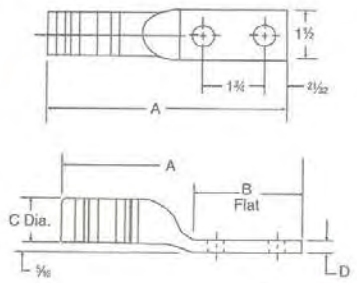
Wire barrel factory-filled with oxide inhibiting compound.

Range-Taking Narrow-Tongue Single-Barrel Lugs

- For 90° C, 600V to 35KV applications
- 1½" wide tongues
- Bolt holes on 1¾" centers

Material: Aluminum

Finish: Tin Plated



CAT. NO.	AL-CU CABLE RANGE	BOLT SIZE	NO. OF COMPRESSIONS TBM12M	NO. OF COMPRESSIONS TBM15	DIMENSIONS (IN.) A	B	C	D	HEX DIE NO.	COLOR CODE
60273N	350-500 kcmil	½"	4	4	6¼	3¼	1⅛	⅜	99H	PINK
60278N	500-750 kcmil	½"	—	4	7¼	3⅛	1¼	½	115H	YELLOW

* 90° C, 600V to 35KV applications

All lugs have 1⅛" wide tongues. Bolt holes on 1¾" centers.

Tooling: ***pp. B76–B92***

Die Selector Chart: ***pp. B93–B95***

Solar farm construction quality: solutions

- Solar farm MV facilities are an "extension" of the utility distribution system
  - need "compatibility"
- Require consideration of utility's construction specifications as "minimum" requirements in Interconnection Agreement
- Inspection & Commissioning program
  - 3-4 weeks before startup, inspection & "punchlist"
  - "final inspection" at time of interconnection commissioning
  - Soon to include inverter inspection

To prevent or limit degradation of power quality and/or reliability in service to other Utility customers, the Utility requires that the Interconnection Customer's facilities shall at all times be compatible with the design, safety, quality and construction of the Utility's electrical facilities, where facilities include, without limitation, overhead distribution lines, underground cable terminations, transformers, and transformer connections. For purposes of the foregoing, "compatibility" shall mean that the Interconnection Customer's facilities shall be designed, constructed and operated such that the Utility's standards for similar facilities are considered "minimum" standards when the Interconnection Customer is designing, constructing and operating its own facilities.

For purposes of the foregoing, the Utility permits Interconnection Customer to access, review, and reprint the Utility's Distribution Construction Specifications, to be used by the Interconnection Customer as minimum standards when designing, constructing and operating its facilities. Utility is not granting permission for the Interconnection Customer for all purposes, but only for the limited purpose of using the standards to assist the Interconnection Customer in meeting the minimum standards of compatibility with the Utility's system. The Interconnection Customer shall retain a professional engineer, licensed in the state where the facilities are being constructed, and shall instruct such engineer to meet the minimum standards set forth above. Further, this access is being granted solely for this project, and it is extended to the Interconnection Customer with the understanding that these designs and standards are the confidential property of the Utility.

Wait, inverter inspections too?

In 2015, Duke asked Advanced Energy (not the inverter mfr) to inspect 41 PV sites.

	# sites compliant	% sites compliant
Documentation: inverter type and number matches interconnection request	19	46%
Documentation: transformer type and number matches interconnection request	14	34%
Sites compliant with the interconnection protection settings specified in the Interconnection Agreement	40	98%
Sites compliant with the interconnection protection settings specified in the Interconnection Agreement	9	22%
Sites which do not have a possible open phase detection issue, based on inverter manufacturer's documentation	23	56%
Sites meeting NEC-required AC ground fault protection or fault detection (NEC 230.95, 250.21b)	16	39%

Yet there's more…

- One site has 830 kVA transformers, each with two secondary windings rated for 415 kVA each
- At one of the transformers, an 830 kVA inverter is wired to one of the two 415 kVA secondary windings, overloading the transformer

Yet there's more…

At one site, improperly rated 600 V insulated wire is used on 690 V inverter AC output circuits

Where do we go from here?

- Duke Energy is working with Advanced Energy (Raleigh NC), Dominion, and other NC utilities to raise the bar
  - Underway: development of a North Carolina model inspection and commissioning standard for utility-scale solar farms
- Duke Energy building a robust inspection & commissioning program
  - periodic inspection requirements also being developed

Contact information

John W. Gajda, P.E.
Manager, DER Operations Support
Duke Energy
411 Fayetteville Street, NC16
Raleigh, NC 27601
T: 919-546-4697

john.gajda@duke-energy.com
www.duke-energy.com