OPGW Engineering 401

Lightning – Theory and Practice

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Registered Continuing Education Program

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PURPOSE STATEMENT/COURSE DESCRIPTION

OPGW Engineering 401 – Lightning:

Theory and Practice will teach attendees about:

- The nature of a lightning strike, including its frequency and intensity
- Resources that a transmission line engineer can draw upon when designing for lighting.
- The Lightning Class levels
- How to deal with lightning damage and the steps to repair it

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LEARNING OBJECTIVES

After this class you will be able to:

1. State that lightning is the **second leading cause of OPGW failure** in the field
2. State the four **components** of a **lightning strike**, and **which one damages** cable.
3. Understand what the **Keraunic Level** defines
4. Determine what level of lightning protection your system might need
5. Understand the **industry standards** for **testing** lightning protection of a cable design
6. Explain the **Lightning Class** levels
7. If lightning damages your OPGW, explain your options on **repair** versus **replacement**

Learning Hub

INCABAMERICA.COM

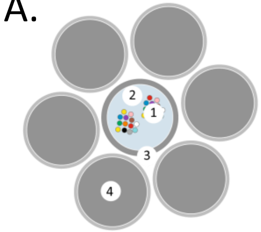
Webinar Rules

- Introduction and sound check
- Presentation: 75 min
- Use chat for questions during presentation
- Q&A (NB! Technical questions only)
- Let's start!

OPGW – Quick Review
The Three Types Used Today

Center Tube Types

A.

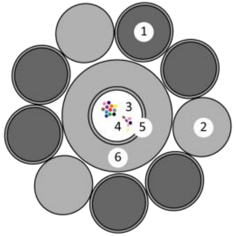


OPGW C — Good

CONSTRUCTION:

1. Optical fiber Corning SMF-28 Ultra
2. Water-blocking gel
3. Stainless Steel Loose Tube (SSLT)
4. Aluminum-Clad Steel Wire (ACS)

B.

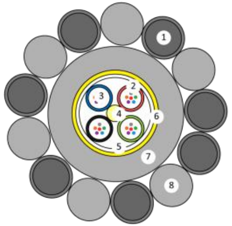


OPGW C — Good

CONSTRUCTION:

1. Aluminum-Clad Steel Wire 20SA
2. Aluminum alloy wire
3. Water-blocking gel
4. Optical fiber Corning SMF-28 Ultra
5. Stainless Steel Loose Tube (SSLT)
6. Aluminum jacket

Aluminum Pipe Type

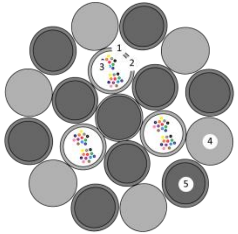


OPGW AP — Better

CONSTRUCTION:

1. Aluminum-Clad Steel Wire 20SA
2. Gel filled loose tube
3. Optical fiber Corning SMF-28 Ultra
4. Central strength member FRP
5. Water-swellable tape
6. Thermal barrier
7. Aluminum pipe
8. Aluminum alloy wire

Stranded Stainless Steel Tube (SSLT) Type



OPGW S — Best

CONSTRUCTION:

1. Stainless Steel Loose Tube (SSLT)
2. Water-blocking gel
3. Optical fiber Corning SMF-28 Ultra
4. Aluminum alloy wire
5. Aluminum-Clad Steel Wire 20SA

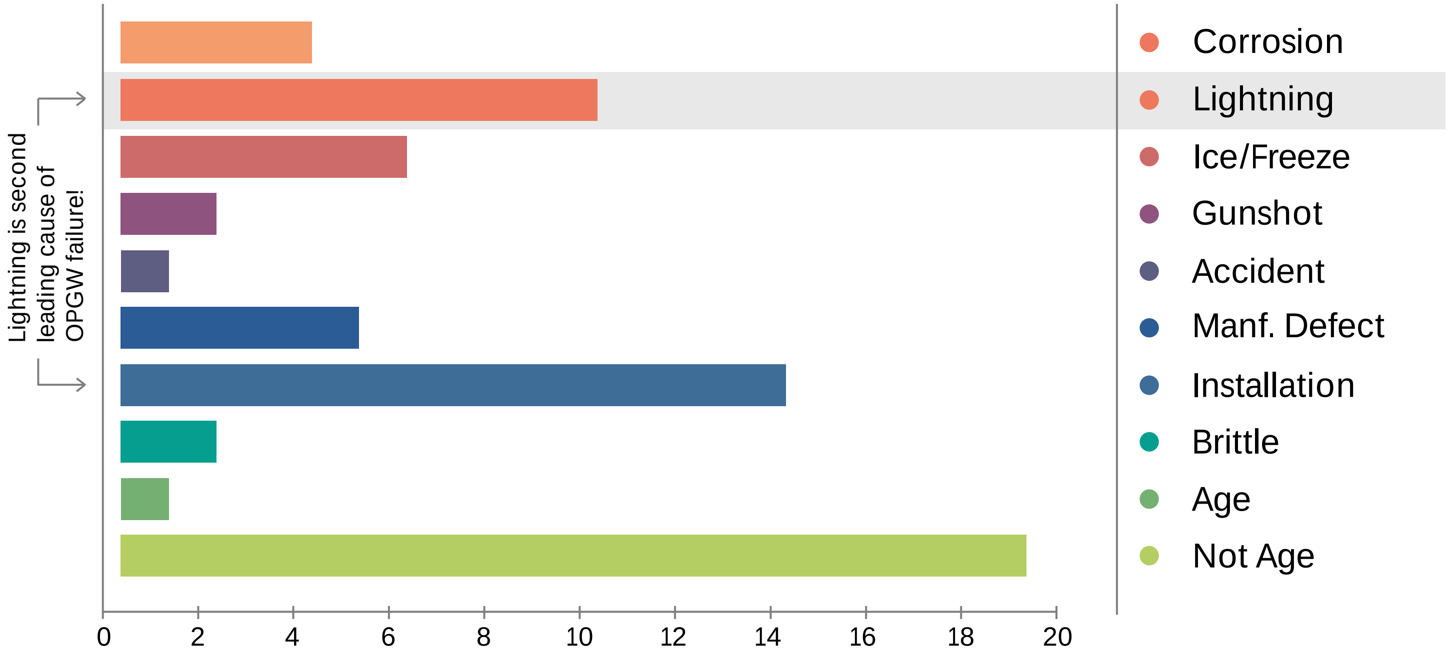
Recall that OPGW

Protects Against Lightning
Provides Telecommunication Capability

- Optical Ground Wire or «OPGW»
  - — Per IEEE 1138-2009 (USA and some countries)
  - — Per IEC 60794-4-10 (Many other countries)
- Primary function of OPGW is to be a shield wire for a transmission line:
  - — To protect the phase conductors from lightning
  - — To provide a path for fault current
- Secondary function: housing optical fiber for data and communications
- In use since the late 1980's

Why is lightning performance important? Consider:

OPGW Failure by Type



Source: 2017 UTC Telecom & Technology presentation by Mike Unser of Salt River Project (SRP) and Dan Newman of Burns & McDonnell

OPGW Lightning Performance

Theoretical Background – What is a strike?

Theoretical Lightning Stroke

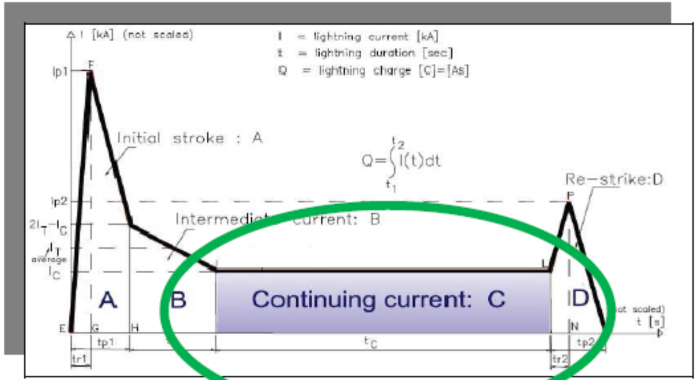
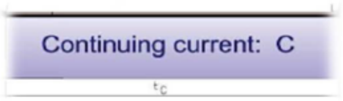


Fig. 1 Conventional waveform of current in a lightning discharge[1]

4 Components:

A. Initial stroke
B. Intermediate current
C. Continuing current
D. Re-strike

We know this component is the most damaging



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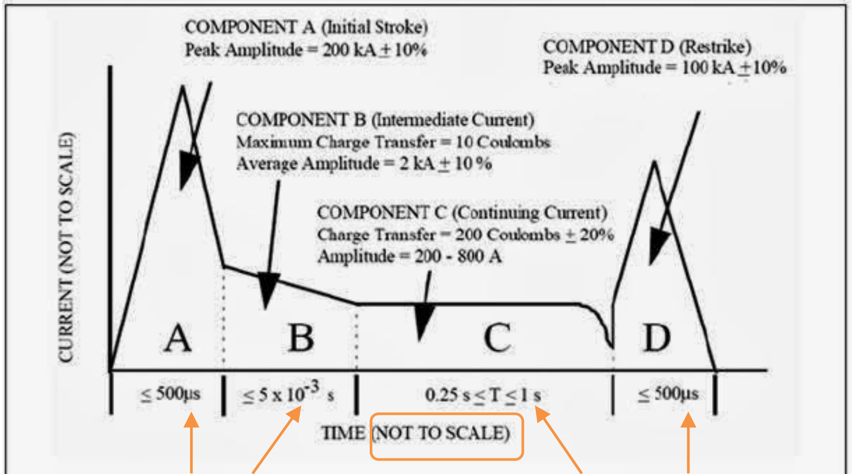
Theoretical Background – Damage from Continuing Current



Representative lightning waveform.

First, observe the amplitudes, but especially the durations:

- A = microseconds = 10^{-6}
- B = milliseconds = 10^{-3}
- C = seconds = 10^{0}
- D = microseconds = 10^{-6}

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Theoretical Background – Damage from Continuing Current

Then, integrate across the wave form (simplifying C):

- A = 50 Amp·seconds (A·s) = 50 Coulumbs (C)
- B = 10 C
- C ≈ 300 C
- D = 24 C

🡐This is why Continuing Current does the damage!
An order of magnitude greater energy!

Remember this "Coulombs thing" for later…

Note: 1 A·s = 1 C and commonly called "Charge Transfer"

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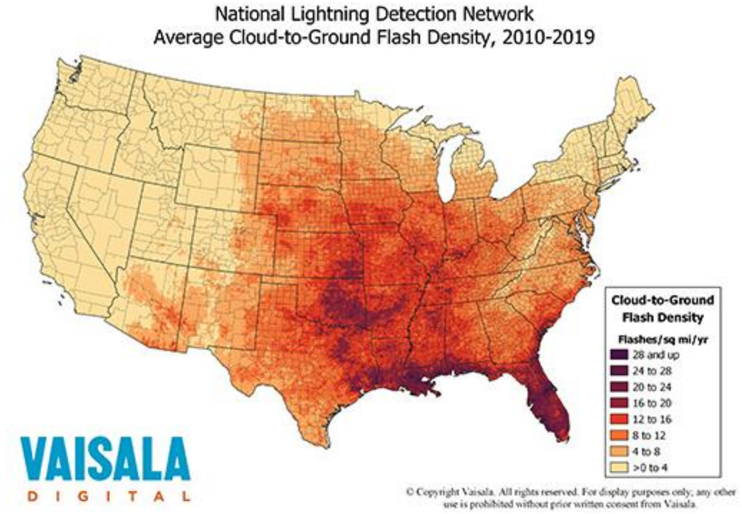
Theoretical Background – Source of Lightning

- Isokeraunic level map will show you the number of flashes that occur in your area each year
- Correlates with likelihood of lightning damage
  - But, not complete. Missing information about duration and intensity



Source: www.vaisala.com/en/products/national-lightning-detection-network-nldn

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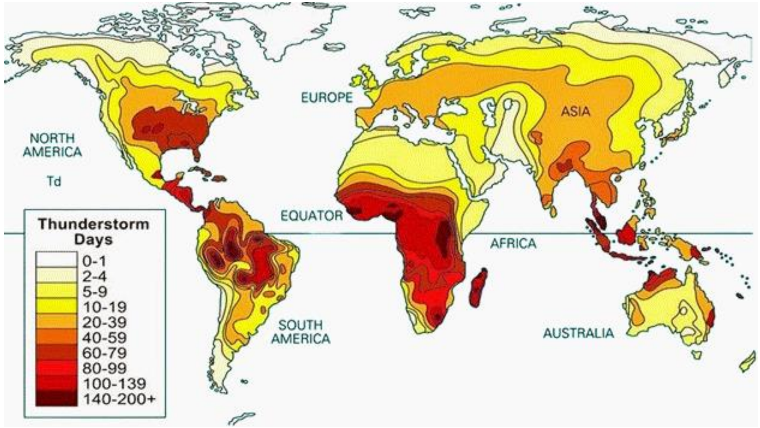
Theoretical Background – "Isokeraunic Level"

"Keraunic Level" (sometimes "ceraunic") average number of days per year with lightning detected

- Originally by sound of thunder
- Then by electronic detection of radio wave disruptions
- Now by satellite using near-infrared detection

Sources include:

- Vaisala (www.vaisala.com) For a fee.
- USA NOAA/National Weather Service refer to Vaisala (Interesting. Big money in lightning data?)
- Others on the internet



Source: electrical-engineering-portal.com

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Application: Putting Theory Into Practice

What resources are available to you as a transmission line engineer?

1. Your utility's experience
2. Data/conclusions from studies
3. The standards for OPGW (Laboratory testing)
4. Cable manufacturers

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Application #1 – Insights from Direct Experience

- What conventional (non-optical) ground wires have been used?
  - 3/8-inch HS/EHS, 7#8 ACS, etc.
- What's the track record of those cables?
  - Any damage?
  - How frequent?
  - To what extent?
  - Broken wires that could be repaired vs complete failure

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Application #1 – Insights from Direct Experience

- What OPGW designs have been used?
- What's the track record of those cables?
    - Any damage?
    - How frequent?
    - To what extent?
    - Broken wires that could be repaired vs complete failure

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Application #1 – Insights from Direct Experience

- Apply “Lessons Learned” from either or both conventional ground wire and OPGW
  - If you are experiencing damage, then face the truth
- Has your utility collected data on the frequency or intensity of lightning in your service area?
  - If so, take advantage of it!

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Application #2 – Insights from Studies

- Ideally, you could find published studies that document the severity of lightning by geographical area
- Unfortunately, comprehensive studies with "actionable data/conclusions" do not exist. What is available is quite limited:
    - Some published data suggests that negative polarity strikes occur more frequently in the field and can be more damaging
    - Other data suggests no significant difference in damage from positive versus negative polarity strikes
- So, not a lot of help here at present, but one can be hopeful for the future

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Application #3 – Insights from the Standards

What insights can you glean from the standards?

Recall, the two standards most commonly used are:

– IEEE 1138-2009

– IEC 60794-4-10

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Application #3 – Insights from the Standards

Evolution of the Standards

1990's = Still early days of OPGW – No standard for lightning until IEC in 1999

- Some manufacturers/utilities doing "Lightning Tests" in the form of "Impulse Tests" roughly equivalent to Component A
- Few, if any, cables fail
  - Component A does little to no damage because energy low
  - Very subjective, very low pass/fail criteria
- Recognition that something standardized and better is needed

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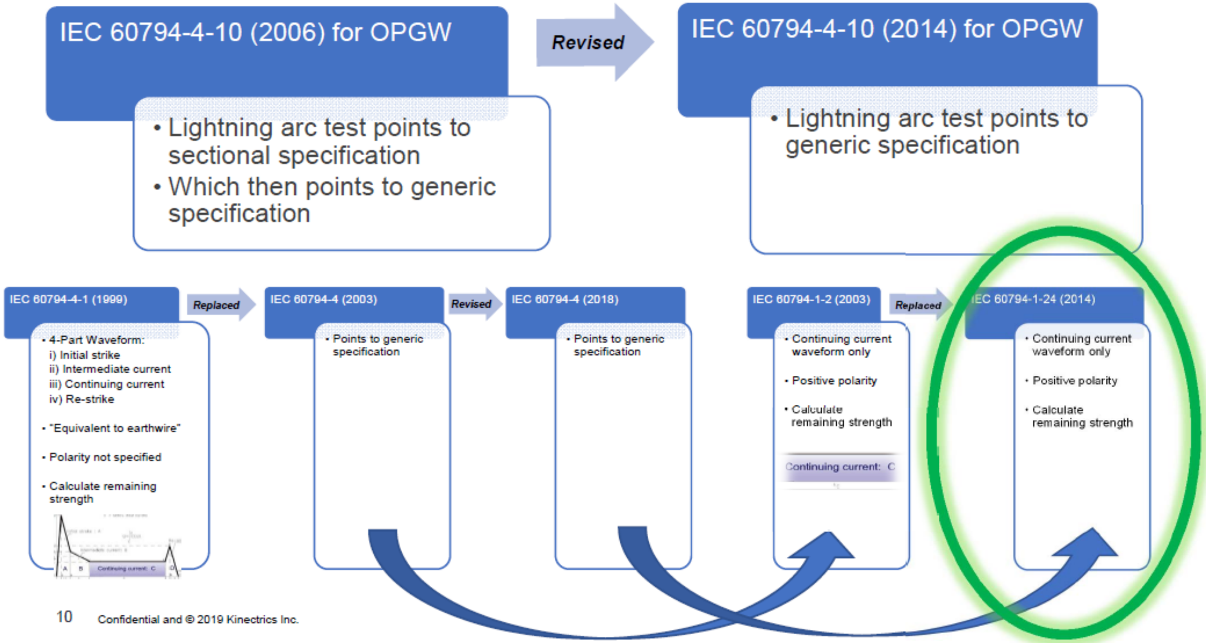
Application #3 – Insights from the Standards

Evolution of the Standards – IEC 60794-4-10:2014



Source: Kinectrics

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Application #3 – Insights from the Standards

Evolution of the Standards – IEC 60794-4-10:2014

Key provisions:

- 5 simulated strikes (“hits”) with positive polarity
- Continuous current component only
- Pass/Fail based on calculating the cable’s remaining strength excluding broken wires.
  - Must be $\geq$ 75% RBS
  - Accurate? What about burnt/damaged wires or possibly annealing?

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Application #3 – Insights from the Standards

Evolution of the Standards – IEEE 1138-2009

IEEE 1138-1994

- No lightning arc test

Revised

IEEE 1138-2009

- Continuing current waveform
- Negative polarity
- Tension Test to measure remaining strength
- Acceptance tied to Rated Tensile Strength (RTS)
- All 5 hits must meet minimum remaining strength requirements

Revised

IEEE 1138-20??

- Under development
- Similar test method as 2009
- Tension Test
- Modified acceptance criteria
- Acceptance tied to Maximum Rated Design Tension (MRDT)
- Statistical approach: 4/5 hits must meet minimum remaining strength requirements

Source: Kinectrics

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Application #3 – Insights from the Standards

Evolution of the Standards – IEEE 1138-2009

Key provisions:

- 5 hits with <u>negative</u> polarity
- Continuous current component only
- Pass/Fail based on <u>testing</u> the cable's remaining strength
  - 2009 – Must be ≥ 75% RBS. (Thinking: NESC 250B plus 15% margin for error)
    - Smaller center tube type designs tend to fail
  - 202? (Pending revision). Must be ≥ MRDT = Maximum Rated Design Tension
    - Smaller center tube type designs MRDT typically 40 – 60% RBS

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Application #3 – Insights from the Standards

Evolution of the Standards – Lightning Class Levels

- Class Level = Standardized “severity levels” based on charge transfer (C)
- Compare/Contrast Test Results – You can use test results for a relative comparison between two or more cable designs
    - Different designs – Design A compared to Design B
    - Different design types (center tube, aluminum pipe, stranded SSLT)
    - Different manufacturers – But, really a function of design differences? (perhaps optical differences might show up?)
- Verification – Can use test results to verify that your cable design can withstand your specified Class Level

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Application #3 – Insights from the Standards

Evolution of the Standards – Lightning Class Levels

Parameter	Class 0	Class 1	Class 2	Class 3
Current (Amperes)	100	200	300	400
Duration (Seconds)	0.5	0.5	0.5	0.5
Charge Transfer (Coulombs)	50	100	150	200

🡐Most severe!

→ Which class should you use? Hold that thought for later, please!

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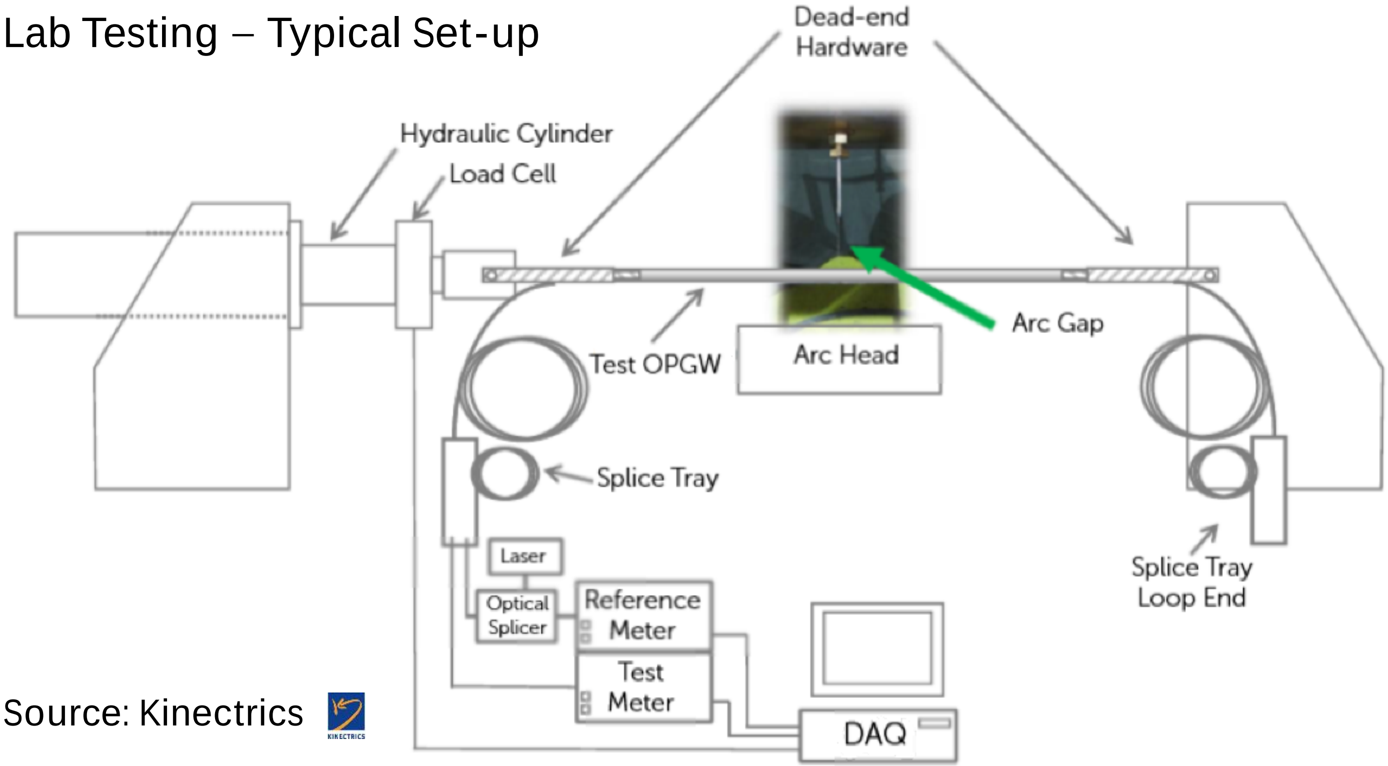
Application #3 – Insights from the Standards

Lab Testing – Typical Set-up



Source: Kinectrics

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Application #3 – Insights from the Standards

Lab Testing – Post Strike Testing Procedures

- After simulated strikes, the remaining strength of the cable is either:
  - IEC Standard – Calculated using remaining, unbroken wires
  - IEEE Standard – Measured by tension testing

Lightning arc damage in center of tension test

13 Confidential and © 2019 Kinectrics Inc.

Cable typically breaks a location of simulated lightning strike, Where wires burnt and/or broken

Source: Kinectrics

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Application #3 – Insights from the Standards

Lab Testing – Applying Acceptance Criteria

- IEC Standard.
    - Calculated using remaining, unbroken wires
    - Ignores "burnt" (= damaged) wires
    - Consequently, these do not factor into the calculated remaining strength (!)

- IEEE Standard.
    - Measured by tension testing
    - Consequently, burnt/damaged wires do reduce the actual remaining strength

Source: Kinectrics

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Application #3 – Insights from the Standards

Lab Testing – Applying Acceptance Criteria, Case Study

- Center tube type design with single outer layer of 8 each ACS wires
- Test strike **breaks 0** wires, but **burns/damages 3**
- Notice the difference between applying the Calculated versus the Measured acceptance criteria:

Calculated	Measured
No broken wires	No broken wires
8 Unbroken ACS wires	3 Burnt wires
Calculated = 100% RTS	Measured = 70% RTS
>75% RTS	<75% RTS
PASS	FAIL

Source: Kinectrics

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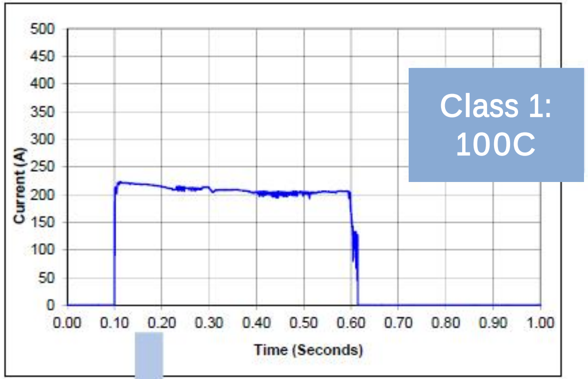
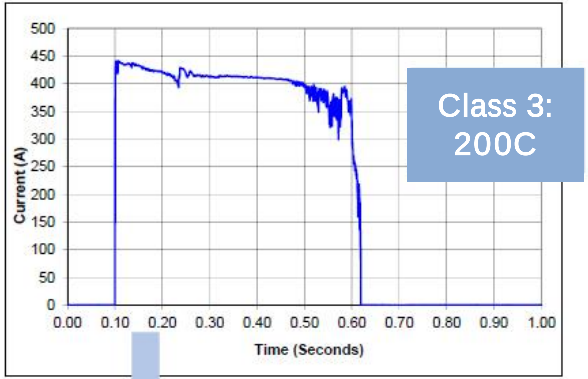
Application #3 – Insights from the Standards

Sample test results



Measured Remaining Strength = 79% RTS



Measured Remaining Strength = 54% RTS

Source: Kinectrics

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Application #3 – Insights from the Standards

Lab Testing – Applying Acceptance Criteria, Case Study Postscript

- Isn't it intuitively obvious to a casual observer that the Measured criterion is better?

  ➔ Possible trade-offs:
    - Added cost and time to a test that is already expensive (≈ $25 k)
    - Some labs can do electrical tests, but not mechanical ones

- What about "improving" the Calculated criterion by treating burnt/damaged wires as if they are broken?

  ➔ A "third" answer only muddies the water more
    - In the example we have considered: 63% RBS remaining (neglecting tube)
    - Now what?

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Application #3 – Insights from the Standards

Bottom Line – What the standards, in particular the lab testing, can do for you

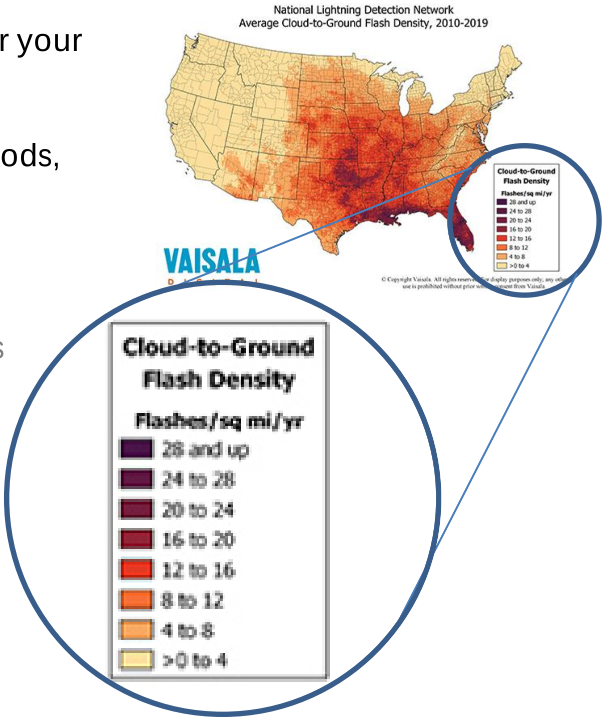
A. Take the Lightning Class Levels and determine a Class Rating for your OPGW

- Using the Scientific Sorcery, SWAG, or Guesstimate Methods, determine a Lightning Class level for your OPGW

- Use isokeraunic data to "put it in the ballpark"

Example <u>only</u>! (This is totally arbitrary because it maps nicely!)

Class 0 (50 C) – 0 to 8
Class 1 (100 C) – 8 to 16
Class 2 (150 C) – 16 to 24
Class 3 (200 C) – 24 and up



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Application – Insights from the Standards

Bottom Line – What the standards and lab testing can do for you, continued

B. Do the testing!

- Does the cable pass the class level?
- Even if yes, consider also…
  - Is the remaining strength adequate for your utility?
  - What if a cable's MRDT is < 60% RBS?
  - How does this compare to your loading criteria? (NESC 250B allows up to 60% RBS)
  - Does your utility consider "Extreme Ice" or "Concurrent Wind and Ice" loading conditions? (NESC 250C and D)

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Application #3 – Insights from the Standards

Bottom Line – What the standards and lab testing can do for you, yet more

C. Is field data available to put results in context?

- If so, compare the severity of lab testing damage to actual field damage
  - My observation is that lab damage seems to be more severe than actual damage reports from the field
- If not, perhaps start collecting it?

D. Adjust your specifications (or expectations?) accordingly and iterate if necessary

- Keep in mind that improving lightning performance will likely come with tradeoffs relative to other design considerations (diameter, weight, cost, etc.)

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Application #4 – Insights from OPGW Manufacturers

- All have had strikes on their cables (real or lab); all have had damage to their cables
  - What have they learned?
  - Filter and compare, challenge when it seems appropriate
- I can only speak to my and Incab's experience
  - Can you really trust those others anyway?

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Application #4 – Insights from OPGW Manufacturers

We at Incab can share our experience (> 25 years) with you…

- General Guideline #1 – A “risk management” approach says that if you design *well* for your fault current, then you will also get good lightning performance too (Free bonus!)
    - Fault current is discussed in detail in OPGW Engineering 101
- General Guideline #2 - There are no other guidelines, because there’s no agreement in our industry on precisely how to design for lightning
    - Nevertheless, we can offer five (5) observations we think are helpful…

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Application #4 – Our Observations

Observation #1 – Size matters

A. A larger wire is less likely to be burned through than a smaller one
   * In response, some utilities have adopted minimum wire sizes
   * Most common is 2.9 - 3.0 mm, but these are arbitrarily chosen
   (that is, there's no data or scientific basis for these values)
   * Empirically citing experience makes sense (Ex: #8 ACS wire (3.26 mm))

B. Overall cable diameter (OD) seems to be a factor as well
   * Spreads the strike energy out over a larger area?
   * In testing, we observed that Cable AP with a larger OD, but smaller outer wires, had fewer broken wires than Cable CA with a smaller OD, but larger outer wires

➔ But, consider the tradeoffs too. Increasing either wire size or cable OD also increases the cost and weight of the cable, and will increase structural loading and perhaps decrease maximum reel length (more pulls and splices?)

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Application #4 – Our Observations

Observation #2 – Material matters

- All else being equal, ACS is better than AY
  (but, galvanized would be better still)

- Consequently, some utilities require all-ACS outer layer
  ➔ But, again, consider the trade offs in cable weight and cost

- Remember that testing on the last slide? There's another wrinkle from it…
  Cable AP with a larger OD and smaller outer wires with an ACS/AY mix, had fewer broken wires than Cable CA with a smaller OD and larger outer wires that were all ACS!

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Application #4 – Our Observations

Observation #3 – Wire count matters too

- X energy (Remember those Coulombs?) will burn Y wires

  ➔ Y of 12 is better than Y of 8

- Recall the testing: It bears this out

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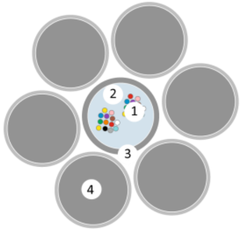
Application #4 – Our Observations

Observation #4 – Design type is a factor also. Rough guidelines are:



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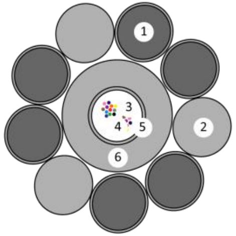

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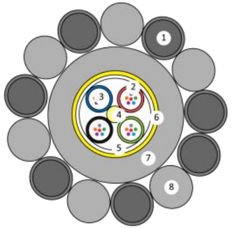

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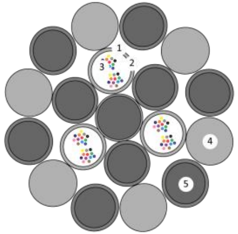

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➔ But, again, consider the trade offs in cable size, weight, and cost

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Application #4 – Our Observations

Observation #5 – Low footing resistance correlates with low incidents of lightning damage

Strikes more likely to hit on or near a structure (75% per the EPRI “Red Book”)

- On the structure means the cable not hit
- Near the structure means hits might be on the supporting accessories:
  - Dead-ends and suspensions have greater mass
    - Acts to dissipate the energy across more metal
  - Armor rods tend to have larger diameters than the cable wires
    - Size effect plus more metal to dissipate the energy
- Assumes the supporting accessories are grounded

➔ Creates conditions that push the odds in your favor

Dealing with lightning damage – It's going to happen eventually

The Repair Option

"Repair rods" may be an option if the optics are still working just fine

Guideline (not a hard rule!):
50% remaining strength
➔ Must confirm with accessory supplier!

— Cable manufacturer can help you estimate remaining strength
— Some cable manufacturers may require higher remaining strength or have other application limitations

Advantages:

- Won't require replacing cable
- Can be quick, if rods on hand

Disadvantages:

- "Estimated" strength = possible error
- Hassle factor of installing
- Sourcing/stocking rods

Dealing with lightning damage

The Replace Option

You may want to, or be forced to, replace a section of cable.
Big Consideration: Time
Remember standard OPGW lead time is 10 – 12 weeks ARO!

Workaround 1

Use ADSS or dielectric cable as a temporary repair

Advantages:

- Can be done with the line still energized
- Can be done quickly

Disadvantages:

- Extra work
- Vulnerability
- Sourcing/stocking the cable and accessories

Dealing with lightning damage

The Replace Option

Workaround 2

Keep an emergency length of cable (on steel reel!) plus accessories (in sealed crate!) on hand

Advantages:

- Can be done quickly
- Permanent
- No scrambling to obtain cable and accessories (assuming you remember where your kit is)

Disadvantages:

- Cost of sourcing and maintaining the kit (beware of "borrowing")
- Figuring out the quantities (How much is enough?)

Tip: OK to reuse tangents, but dead-ends must be new

Dealing with lightning damage

The Replace Option

How much to replace?

- **Just the affected span** = Adds two splice points but requires less cable and accessories
- **Span to closest** = Adds one splice point but requires more cable and accessories
- **Entire segment** = Doesn’t add a splice point but requires much more cable and accessories. Seems like overkill

In case you were wondering: Typical splice loss at 1550 nm is 0.01 dB, and the maximum is < 0.05 dB.

Lightning – Theory and Practice

Recap

- **Assess** your utility's lightning performance needs and experience to date
- **Use** all the resources available to you: experience, studies, standards, suppliers
- **Decide** if your utility's specifications should include a Lightning Class Level or other design requirements specific to lightning for your OPGW
- **Test** to confirm that your OPGW meets your requirements and adjust accordingly to what the testing shows
- **Prepare** for the eventuality of lightning damage

Thank you!

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