What is Optical Ground Wire?

- aluminum clad steel wire
- aluminum alloy wire
- aluminum pipe
- stainless steel tube
- optical fibers
Engineering Considerations

• What happens if the OPGW is damaged?
OPGW Thermal Limitations

- Fiber optic glass has >300°C temperature limit.
- Excessive heat can anneal supporting conductor, 180-200°C temp limit is common.
- OPGW manufacturer cut-sheets provide $I^2t$ (kA²*s) transient current thermal rating.

<table>
<thead>
<tr>
<th>Electrical</th>
<th>DC Resistance at 20°C</th>
<th>Rated Short Circuit Current (0.5 sec)</th>
<th>Rated Fault Current (40°C ambient initial/200°C max. final)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.2128 Ω/mile</td>
<td>8.5 kA</td>
<td>35.9 (kA)²s</td>
</tr>
<tr>
<td></td>
<td>0.7536 Ω/km</td>
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</tbody>
</table>
1. Establish mutually-agreed worst-case fault sequence of events for design
   » Initial DC offset of fault
   » Pre-fault contingency
   » Reclosing effects
   » Fault clearing with stuck breaker
2. Simulate faults for each step of SOE
3. Determine fault clearing time
4. Calculate $I^2t$
5. Mitigate design
Case Study – OPGW Retrofit

- Re-conductoring of double circuit 115 kV line – existing monopoles, single shield position.
- OPGW Selection – 109.0 kA²s; matches mechanical properties of existing shield.
- Line Protection – dual pilot schemes (POTT and DCB); five-cycle normal clearing.
- Breaker Failure Protection – 15 cycle clearing.
- Reclosing Philosophy – one shot taken from one terminal on dead 115 kV line.
With 5-cy+15-cy = 20-cy fault duty, max fault kA through OPGW is 
\[
[109.0 \text{ kA}^2 \text{s} \div (20/60 \text{ s})]^{1/2} = 18.09 \text{ kA},
\]
neglecting DC offset factor and infeed effects.

From utility protection study short circuit model, actual highest branch current =~ 30.0 kA symmetrical with both terminals closed and strongest infeed removed prior to fault.

Utility decided on a 10% fault current growth factor.
DC Offset Heating Factor

- $X/R = 5.14$ of system supplying the line
- Multiplying factor to account for initial DC offset
  $= 1.078$ for $X/R = 5.14$ and five-cycle fault
Case Study – OPGW Retrofit

Worst Case SOE

• Utility decided that normal clearing then reclose into stuck breaker too unlikely to justify as design basis.
• Two-shot normal clearing produces less heating than single stuck breaker event.
Case Study – OPGW Retrofit

- Thermal rating required – stuck breaker:
  \[(1.078 \times 30.0 \text{ kA})^2 \times (5/60 \text{ s}) + (30.7 \text{ kA})^2 \times (10/60 \text{ s})\]
  \[= 247.9 \text{ kA}^2\text{s}\]

- No fault current growth factor included yet!
Mitigation Design

- Model line constants with greater accuracy using detailed line design.
- Re-build system in alternate software to model footing resistances and measure OPGW branch current specifically.
- 10% fault current growth factor included by reducing equivalent source impedances by 10%.
- Determine structure footing resistance by taking actual soil resistivity measurements, modeling soil and grounding design.
Results of Case Study – No Mitigation

- First verified conversion of boundary equivalent model into new software. Results varied less than 1% between models.
- Remodeling line constants reduced overall fault current by ~12%, relatively insensitive to footing resistance.
- Soil and grounding model yielded 40 ohm footing resistance even with 150’ long “crow’s feet” counterpoise.
- With footings added, OPGW current was 16% less than total branch current.
- Revised model reduced heating by 30%, but further reduction was required.
Mitigation Options – Enhanced Grounding

• Utility would normally design structure grounding to achieve 15 ohm resistance.
• Changing footing resistance to 15 ohm had little effect on overall fault current, but OPGW return current was reduced by 12%.
• Total thermal duty was reduced to 110.2 kA^2s.
• Given extensive bedrock, achieving 15 ohm resistance was not deemed cost effective.
Mitigation Options – Add Second Conductor

- Continuous counterpoise or second OHGW
- Effectively reduce current through each path by ~50%, total heating to ~25% of original.
- May not be cost-effective for retrofit projects.
Mitigation Options – Increase OPGW Size

- OPGW size can be increased in sections with worst heating, then step down in size as allowed.
- Not an particularly effective option with short lines.
Mitigation Options – Reduce Clearing Time

• Already using fastest relays available and tripping diodes for failed breaker clearing.
• Utility approved reducing breaker failure delay for 13-cycle total clearing.
• Reduced fault duration reduced heating by 15%.
Mitigation Options – Isolate OPGW from substation ground grid

- Isolating the OPGW from the substation ground grid at both ends reduced worst-case OPGW current from 24.66 kA to 21.29 kA (15.8%), total heating to 82.37 kA²s.
Mitigation Options – Isolate OPGW from substation ground grid

- OPGW isolation design needs 60 Hz wet frequency withstand rating greater than voltage rise on OPGW during ground fault.
- Isolating OPGW increases ground grid current split factor at substation, may require ground grid design mitigation.
- Isolated OPGW affects ground fault currents and must be accounted for in protection short circuit model.
109 kA²s OPGW.
Reduced breaker failure time delay for 15 cycle total clearing.
Standard “crow’s feet” structure grounding design.
OPGW is isolated from ground grid at both ends.
10% fault current growth factor.

Approved mitigated design from case study
Questions?