Covered Conductor - Everything You Need To Know (Compendium)

October 3, 2019

Purpose

- There has been a vast amount of literature search, testing, calculation, benchmarking and standards development by T&D Engineering for the deployment of Covered Conductor
- As a result, multiple work documentation on various topics concerning Covered Conductor has been created for supporting the issuance of SCE specifications, design and construction standards for covered conductor
- These topics on Covered Conductor are summarized on the "Table of Contents" slide.
- The purpose of this slide deck is to consolidate and condense the key thoughts of these works into a single document, providing a comprehensive overview of covered conductor

Table of Contents

Chapter I
What is Covered Conductor?
Why Covered Conductor?

1. The Evolution of Covered Conductor Design

This section introduces the high-level understanding of Covered Conductor and how it has evolved from a simple model in the early 1970s to a robust design today that mitigates contact issues and achieves long service life

A Brief History

- Covered Conductor has been used by utilities since the 1970s in Europe and the U.S.
  - Key driver: reliability improvement in dense vegetation areas, such as forests in Scandinavia, the U.K., New England, etc.
- Other drivers expand the use of covered conductors:
  - Tokyo, Japan: public safety in dense population
  - Southeast Asia (Thailand, Malaysia): animal protection (snakes, monkeys, rodents), and dense vegetation, also public safety in downtown Bangkok
- Reduction of “bushfires” has become a key driver for replacing bare with covered conductor in Australia
- Over the years, significant development in the covered conductor design led to improved performance and extended life

Nomenclature of Covered Conductor

- Covered conductor is a widely accepted and used term for distinguished from bare conductor
- The term indicates a conductor being “covered” with insulating materials to provide incidental contact protection
- Covered conductor is used in the U.S. in lieu of “insulated conductor”, which is reserved for grounded overhead cable
- Other parts in the world use the term “covered conductor”, “insulated conductor”, “coated conductor” interchangeably
- Covered conductor is a generic name for many sub-categories of conductor design and field construction arrangement
- Covered conductor in the U.S.:
    - Tree wire
        - Term was widely used in the U.S. in 1970’s
        - Associated with simple one layer cover
        - Used to indicate cross-arm construction
    - Spacer cable
        - Associated with construction using trapezoidal insulated brackets for suspending covered conductor
    - Aerial bundled cable (ABC)
        - Installation of underground cable on poles with benefits of being grounded
- Covered Conductor in Europe:
    - SAX, PAS/BLX, BLX-T are some names for covered conductor used in Scandinavia for installations in forests
    - CC/CCT are covered conductor and covered conductor with extra thickness are used in Australia, the Far East
- Covered Conductor at SCE:
    - The term “Covered Conductor” was introduced to SCE standards in Q1, 2018, previously, the term "tree wire" was used
    - SCE is more familiar with “aerial cable” to indicate field-bundled underground cable (with or without jacket) prior to 2000’s, and manufacturer “pre-bundled” underground cable on air (ABC) in the 2000’s
    - Current SCE specified Covered Conductor is more robust than CCT with has better UV protection

Single Layer Covered Conductor

- Characteristics:
  - Single Layer
  - Typically, Low Density Polyethylene (insulating material)
  - Covering Thickness ranges from 0.091 to 0.130 inches
- Lower impulse strength than the two or three layer design
- Provides some resistance to outages caused by tree and wildlife contact

Two Layer Covered Conductor

- Characteristics:
  - Two Layers
    - Layer A: Polyethylene (PE)
      - Insulating material
      - 0.080 inches
    - Layer B: High Density Polyethylene (HDPE)
      - Insulating Material
      - Tougher than layer A
        - Abrasion Resistant
      - 0.080 inches
- Higher impulse strength than the single layer design

Three Layer Covered Conductor

- Characteristics
  - Three Layers
    - Layer A: Conductor Shield
      - Semiconducting layer
      - Reduces Voltage Stress
    - Layer B: Polyethylene Layer
      - Insulating Layer
      - Can be crosslinked (XLPE)
    - Layer C: Polyethylene Layer
      - Insulating Layer
      - Can be high density and/or crosslinked
- Higher impulse strength than the single layer design and two layer design

SCE's Evolution

Single Layer

- 150 mils HDPE

3 Layer 75°C Rated

- 15 mils conductor shield
- 75 mils LDPE Inner Layer
- 75 mils HDPE Outer Layer

3 Layer

90°C Rated

- 15 mils conductor shield
- 75 mils XL-LDPE Inner Layer
- 75 mils XL-HDPE Outer Layer

Covered Conductor Installation Options

- Cross-arm Construction
  - (aka Tree Wire)

Most of SCE installations on Cross-arm (SCE uses grey to reduce the impact of sun light heating effect, thus increase ampacity)

- Compact Construction
  - (aka Spacer Cable)

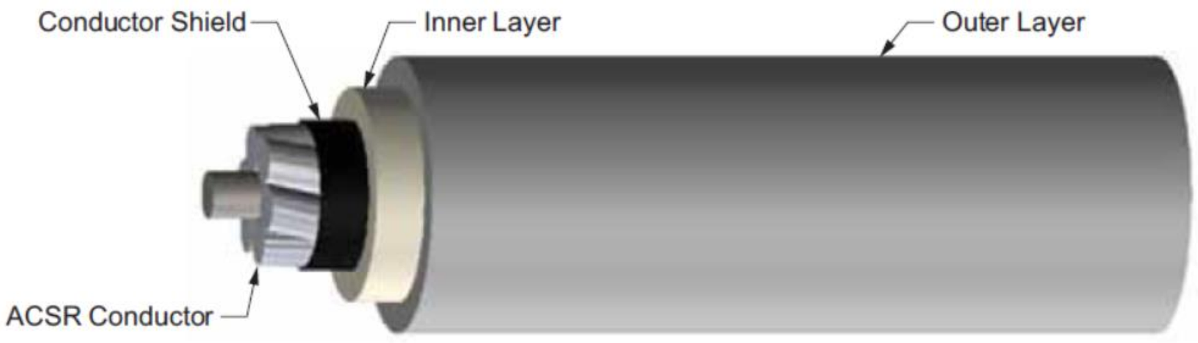
Some installations will be space cable (e.g. replacement of tree attachments)

2. SCE Covered Conductor Design

This section provides more insights of SCE Covered Conductor Design – layer by layer and the functions of each layer (sheath)

SCE Design

- Three Layer Covered Conductor
  - Conductor
    - Aluminum Conductor Steel-Reinforced (ACSR)
    - Hard Drawn Copper (HDCU)
  - Conductor Shield
    - Semiconducting Thermoset Polymer
  - Inner Layer
    - Crosslinked Low Density Polyethylene
  - Outer Layer
    - Crosslinked High Density Polyethylene

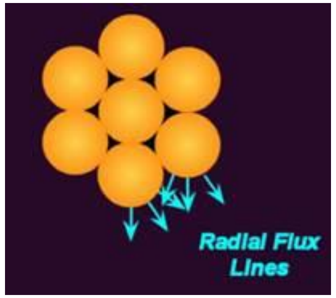


Conductor

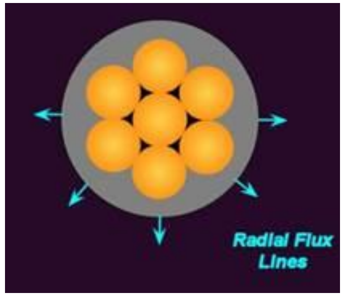
- Aluminum Conductor Steel-Reinforced (ACSR)
  - Sizes
    - 1/0 AWG (6/1 Strand)
    - 336.4 AWG (18/1 Strand)
    - 653 AWG (18/3 Strand)
- Hard Drawn Copper (HDCU)
  - For use in coastal areas (within 1 mile of the coast)
    - Copper is more resistant to corrosion than Aluminum
  - Sizes
    - #2 AWG (7 Strand)
    - 2/0 AWG (7 Strand)
    - 4/0 AWG (7 strand)

Conductor Shield

- Material: Semiconducting Thermoset Polymer
- Reduces stress concentrations caused by flux lines from individual conductor strands.
  - Transforms strands into a single uniform conducting cylinder



Flux lines without a conductor shield

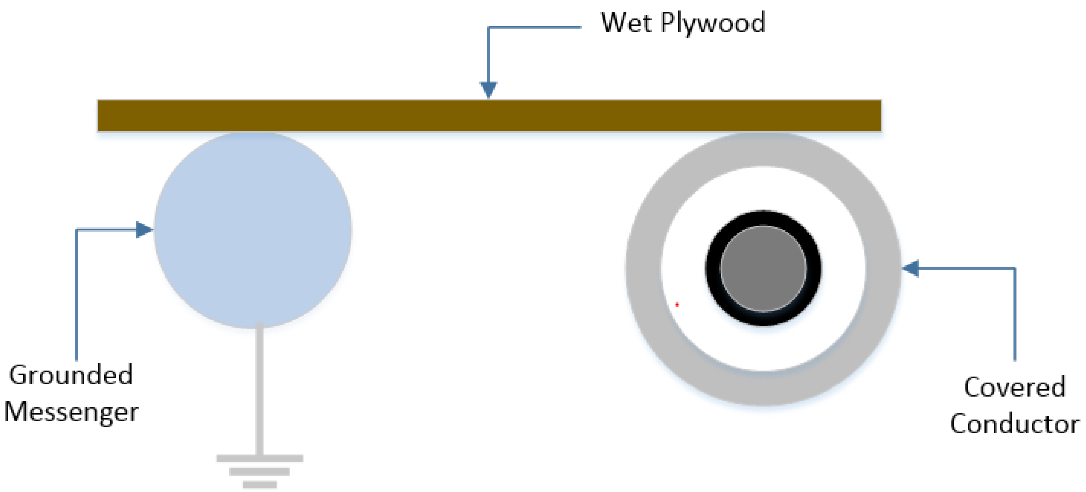


Flux lines with a conductor shield

- The reduction of electrical stress, especially if the covered conductor is in contact with another object, will help preserve the integrity of the insulation and lengthen the useful service life of the covered conductor.

Conductor Shield – Wet Wood Testing

- Subjected the covered conductor to higher-than-normal voltages for its typical use and design to accelerate the time it takes for the covered conductor to fail
- 35kV Covered Conductor subjected to 30 kV did not fail since it was exposed to voltage it was designed for
- Conclusion: Conductor shield allows the covered conductor to withstand contact for a longer period of time



Accelerated Testing - Days to Failure			
Voltage Applied	**15 kV CC - No Conductor Shield**	**15 kV CC - With Conductor Shield**	**35 kV CC - With Conductor Shield (Experiment Control)**
30 kV	21.3 Days	35.7 Days	Testing stopped without failure after 141.9 Days
40 kV	2.08 Days	9.2 Days	Not Tested
50 kV	0.02 Days	0.16 Days	Not Tested

Inner Layer

- Material: Crosslinked Low Density Polyethylene (XL-LDPE)
- Insulating Layer
  - Contributes to the high impulse strength of the covering, which will protect the conductor from phase-to-phase and phase-to-ground contact
- Crosslinking will allow the material to retain its strength and shape even when heated

Outer Layer

- Material: Crosslinked High Density Polyethylene (XL-HDPE)
- Insulating Layer
  - Contributes to the high impulse strength of the covering, which will protect the conductor from phase-to-phase and phase-to-ground contact
- Abrasion and Impact Resistant
- Environmental Stress-Crack Resistant
- Track Resistant
- UV Resistant
- Crosslinking (XL) will allow the material to retain its strength and shape even when heated
- HDPE uses Titanium Dioxide as the most effective UV inhibitor, and providing the best track resistant

Temperature Rating

- Normal Operation: 90ºC
- Emergency Operation: 130ºC
- Short Circuit Operation: 250ºC

Covered Conductor vs. Bare Comparison

- ACSR Covered Conductor

Conductor Size (AWG)	Conductor Type (Stranding)	Cover Type	Weight (lb/ft)	Overall Diameter (in)	Ampacity per Conductor/ (Amps)
1/0	ACSR (6x1)	XL-HDPE (165 mils)	0.277	0.728	271
336.4	ACSR (18x1)	XL-HDPE (165 mils)	0.564	1.014	550
653.9	ACSR (18x3)	XL-HDPE (180 mils)	0.973	1.313	835

- ACSR Bare

Conductor Size (AWG)	Conductor Type (Stranding)	Cover Type	Weight (lb/ft)	Overall Diameter (in)	Ampacity per Conductor/ (Amps)
1/0	ACSR (6x1)	N/A	0.146	0.398	280
336.4	ACSR (18x1)	N/A	0.365	0.684	605
653.9	ACSR (18x3)	N/A	0.677	0.953	920

Covered Conductor vs. Bare Comparison

- Copper Covered Conductor

Conductor Size (AWG)	Conductor Type (Stranding)	Cover Type	Weight (lb/ft)	Overall Diameter (in)	Ampacity per Conductor/ (Amps)
#2	HDCU (7)	XL-HDPE (165 mils)	0.316	0.622	240
2/0	HDCU (7)	XL-HDPE (165 mils)	0.569	0.744	367
4/0	HDCU (7)	XL-HDPE (165 mils)	0.845	0.852	488

- Copper Bare Conductor

Conductor Size (AWG)	Conductor Type (Stranding)	Cover Type	Weight (lb/ft)	Overall Diameter (in)	Ampacity per Conductor/ (Amps)
#2	HDCU (7)	N/A	0.205	0.292	260
2/0	HDCU (7)	N/A	0.411	0.414	405
4/0	HDCU (7)	N/A	0.653	0.522	540

3. Contact with Foreign Object

This section demonstrates how Covered Conduct reduces ignition risks during contact with foreign object or other conductor by performing a complex engineering analysis and testing impacts of contact on Covered Conductor

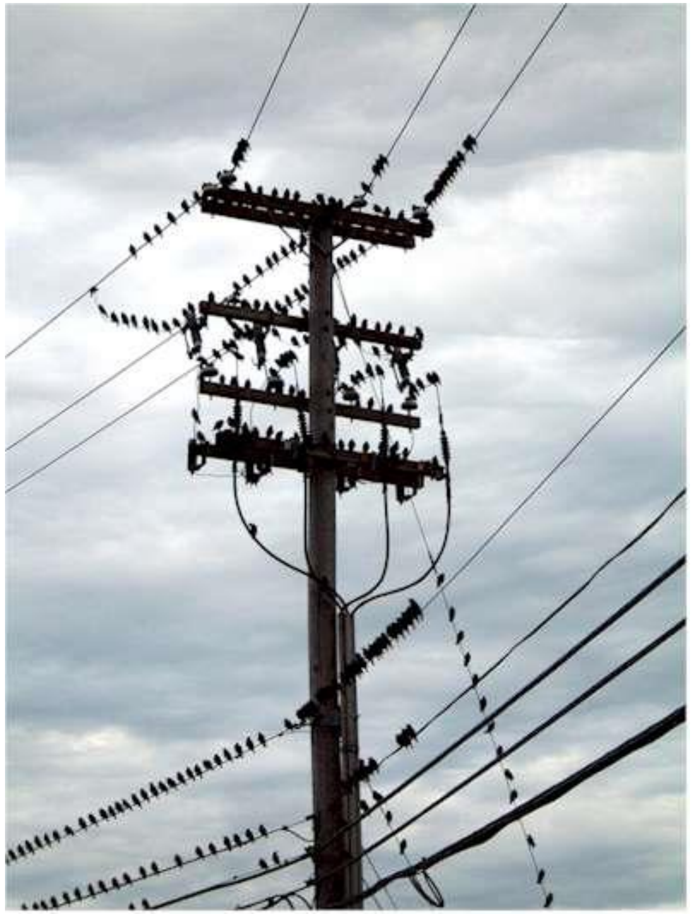
Contact from Objects with Bare Wire

Vegetation Contact

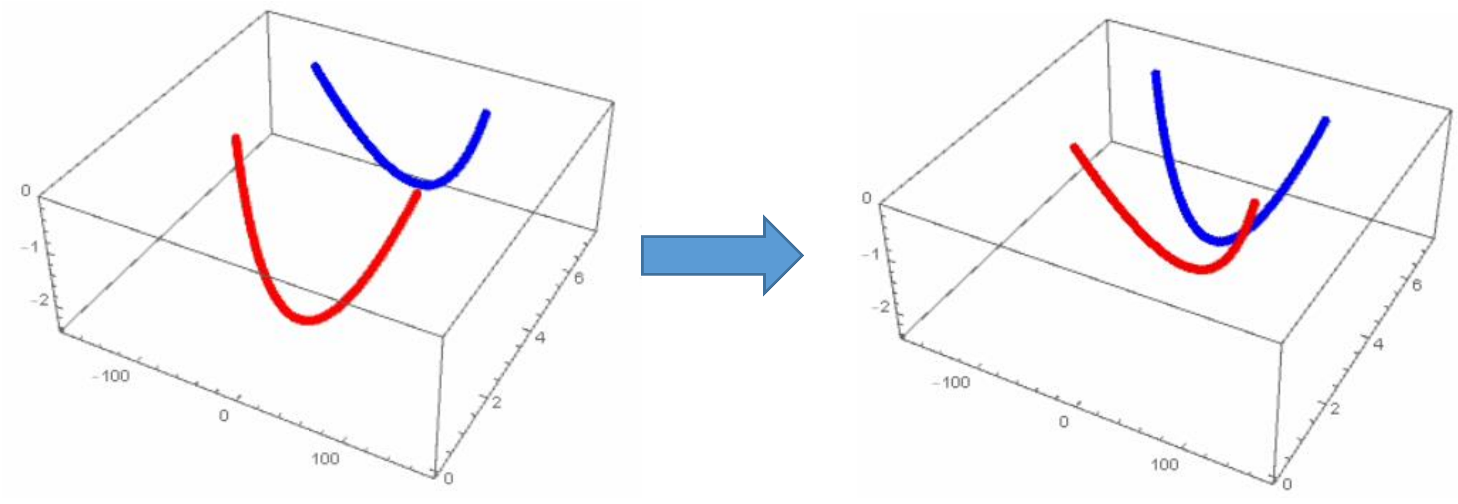
- Branches grow into line
- Wind blow trees around line
- Wind blows palm fronds into lines

Metallic Balloon Contact

Contact from Objects with Bare Wire



Wildlife Contact



Conductor-to-Conductor Contact

Contact from Object

- Covered conductors will prevent incidental contacts that cause phase-to-phase and phase-to-ground faults caused by:
  - Vegetation/Palm fronds
  - Conductor slapping
  - Wildlife
  - Metallic Balloons
- Analysis of computer modeled scenarios and field testing supports that covered conductor will prevent faults caused by incidental contact.

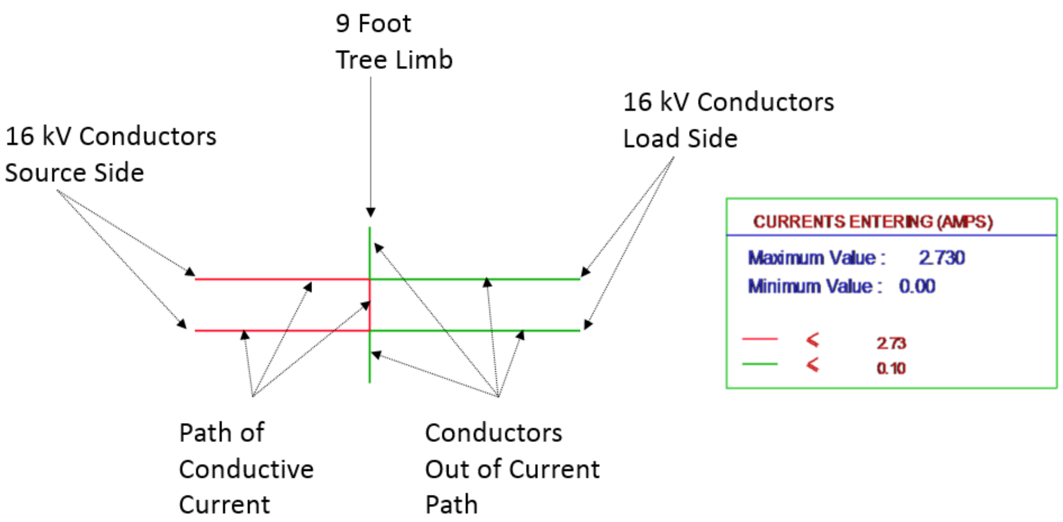
Contact with Foreign Object Using Computer Modeling & Simulation

- An SCE study analyzed the effectiveness of the covering in preventing phase-to-phase faults due to incidental contact
- The study also analyzed the energy absorbed by the foreign object when contact with two covered conductor is significant low and not sufficient to start a fire.
- Complex electric power engineering program tools used for computer modeling:
    - PSCAD (Power Systems Computer Aided Design)
    - CDEGS (Current Distribution, Electromagnetic Interference, Grounding and Soil Structure Analysis)
- Scenarios Modeled:
    - Tree/Vegetation phase-to-phase contact
    - Conductor Slapping
    - Wildlife phase-to-phase contact
    - Metallic Balloon phase-to-phase contact

Example of Computer Modeling & Simulation Results for Tree Contact (CDEGS)

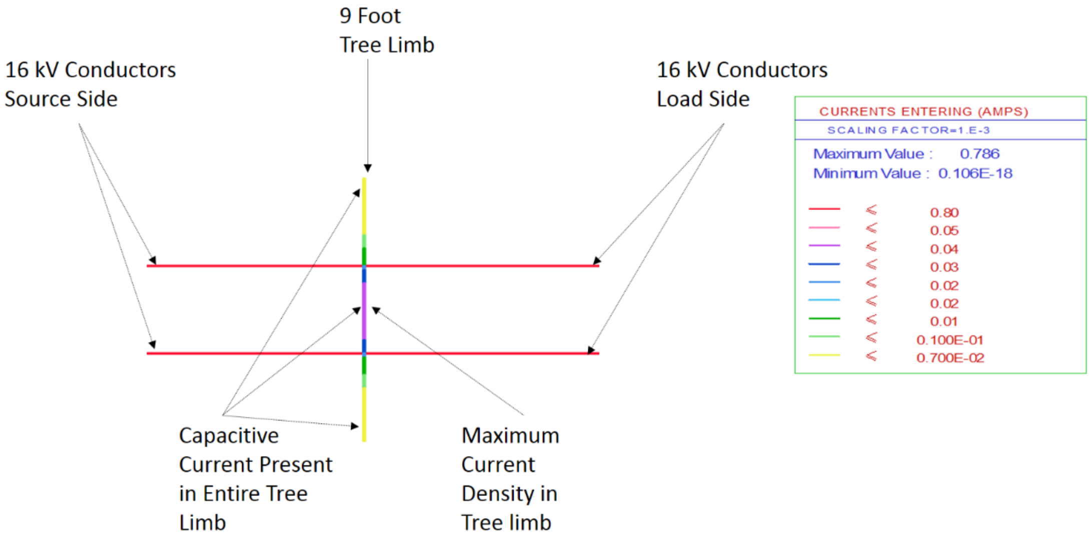
Case 1: Tree on Two Bare Conductors

Maximum Current through object: **2.7 A**



Case 2: Tree on Two Covered Conductors

Maximum Current through object **0.04 mA**



Study Conclusion

- The analysis concluded that a foreign object contact with covered conductors will not cause a fault
- The results showed that covered conductors reduce the energy from tens of thousands of watts to well under one milliwatt.
- This reduction is expected to be sufficient to prevent ignition

Simulation Method	Conductor Type	Current in Branch	Resistance of Branch	Power into Branch
PSCAD	Bare Conductor	2800 mA	5800 Ω	45,472 W
	Covered Conductor	0.18 mA	5800 Ω	0.00019 W
CDEGS	Bare Conductor	2730 mA	5800 Ω	43,227 W
	Covered Conductor	0.04 mA	5800 Ω	0.00001 W

Field Testing

- Field testing was performed at SCE's EDEF Test Facility in Westminster to validate the computer model study
- Tests performed for contact with covered conductors only
- No tests performed for contact with bare conductors, because this information is well studied by the industry
- Scenarios tested:
  - Tree/Vegetation phase-to-phase contact
  - Conductor Slapping
  - Wildlife phase-to-phase contact
  - Metallic Balloon phase-to-phase contact

Palm Frond Contact

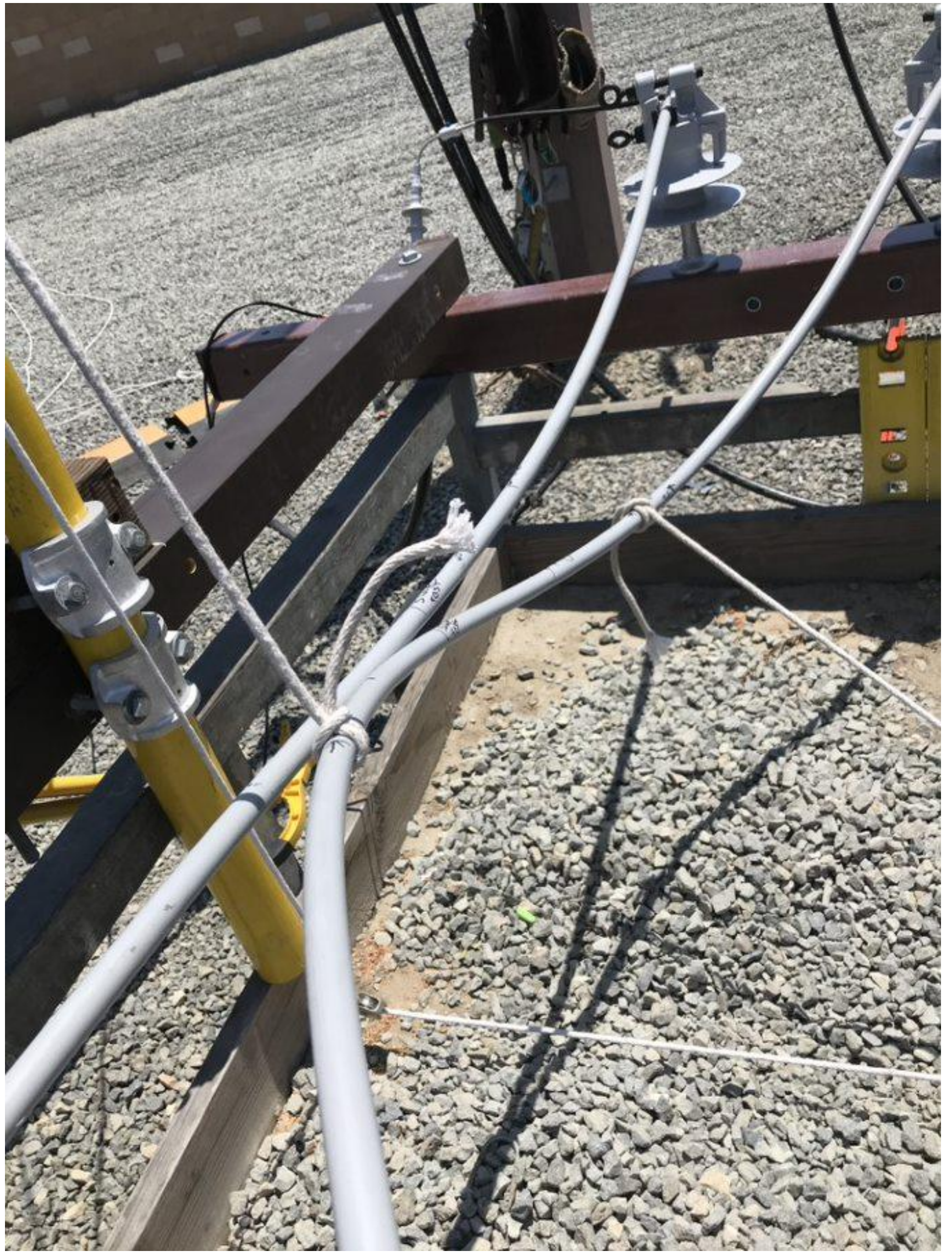
- Energized at 12 kV
- Observations
  - No arcing
  - No damage to the covered conductor
  - No damage to the palm frond

Tree Branch contact

- Energized at 12 kV
- Observations
  - No arcing
  - No damage to the covered conductor
  - No damage to the tree branch

Conductor Slapping

- Energized at 12 kV
- Observations
  - No arcing
  - No damage to both covered conductors



Wildlife Contact

- 700 Ω resistor simulated animal contact
- Energized at 12 kV
- Observations
  - No arcing
  - No damage to the covered conductor
  - No damage to resistor

Metallic Balloon Contact

- Energized at 12 kV
- Observations
  - No arcing
  - No damage to the covered conductor
  - No damage to the metallic balloon

Field Test Conclusion

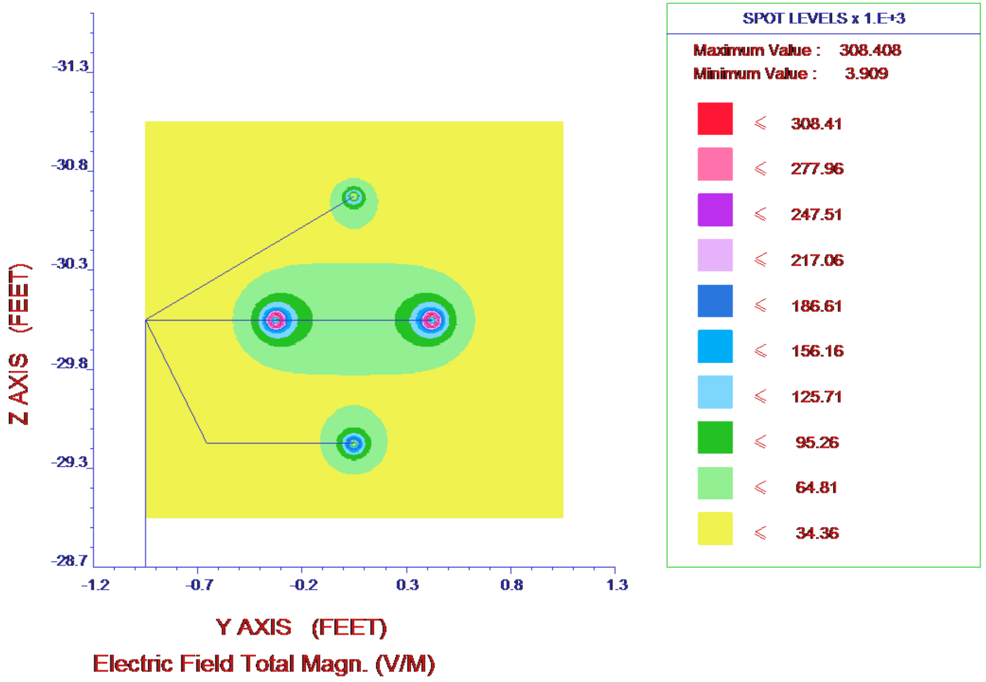
- Field testing validated that covered conductor will prevent faults and reduce the chance of ignition due to incidental contact

Simulated/Test Subject	Current		Energy	
	Simulation Current with Test Subject (mA)	Empirical Current with Test Subject (mA)	Power -Simulation (Watts)	Power – Empirical Testing (Watts)
Palm Frond	0.005	0.001	0.00525	0.00021
Brown Branch	0.006	-0.001	0.17	0.0048
Green Branch	0.003	0.001	0.000012	0.0000014
728 Ohm Resistor Ph-Ph	0.004	0.044	0.000000012	0.0000015
1024 Ohm Resistor Ph-Gnd	0.007	0.052	0.000000050	0.0000028
1024 Ohm Resistor Ph-Ph	0.005	0.03	0.0000000256	0. 0000009216
Conductor-to-Conductor	0.042	0.008		
Metallic Balloon	0.009	0.128	0.00000000030	0.000000066

4. Spacer System – Contact with Objects and Dielectric Strength

CDEGS Simulation

- A CDEGS model was made according to spacer wire dimensions where all three covered conductor phases and a messenger wire are 8 inches apart.
- The dielectric breakdown of air is 3 MV/m. The simulation results show that the maximum electric field produced with this arrangement is lower than the threshold for the dielectric breakdown of air by a factor of 10.

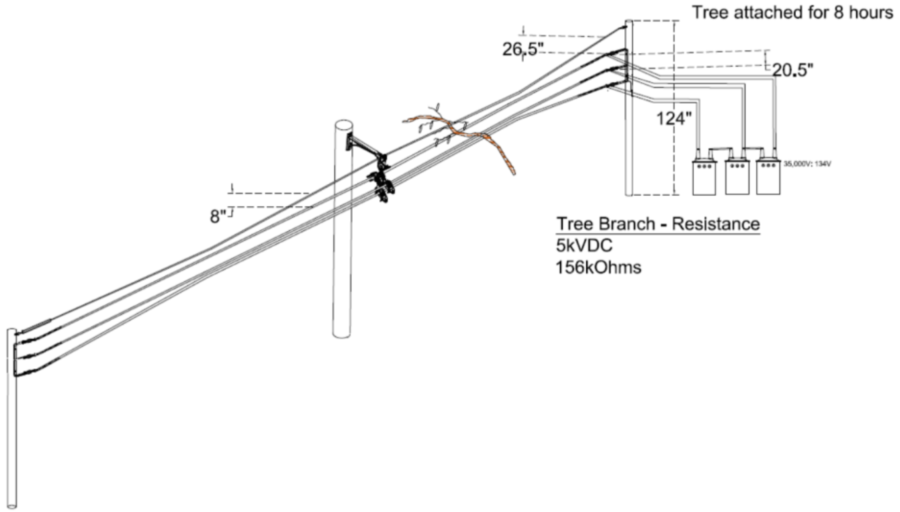


Dielectric Breakdown of Air	Maximum Electric Field Produced w/ 8-inch Spacer Wire Arrangement
3 MV/m	0.3 MV/m

Wet Branch Test Results

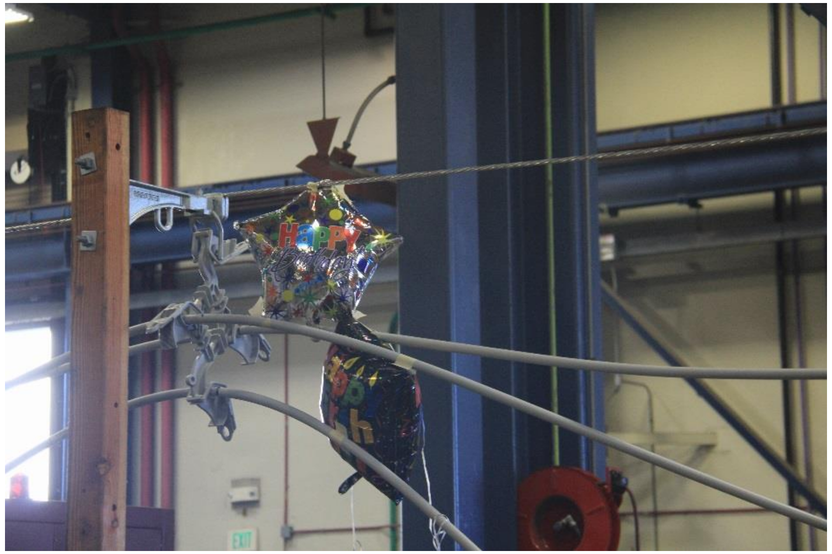
- The test simulates scenario of a tree falling into a spacer cable system, assuming the tree brings all phases and the messengers together.
- The covered conductor was designed for 15kV and a voltage of 35kV was applied
- Spacers sprayed hourly with a consistency similar to a fog with salt mixture.
- Branch moisture randomly measured with a content of 26%.
- Results: Covered conductor withstood contact with no failure

Test Subject	Time Duration	Empirical Average Current with Test Subject
Tree Branch	8 Hours	0.865A

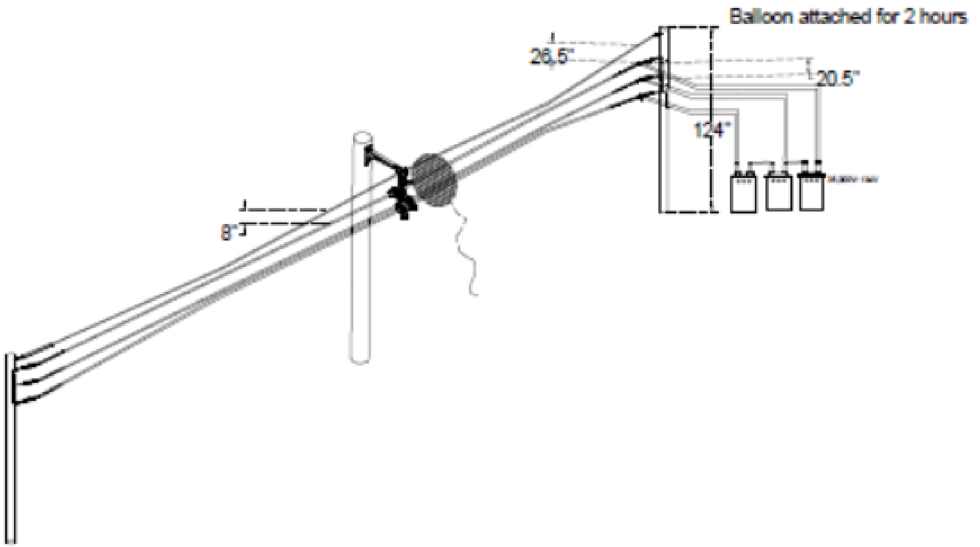


Metallic Balloon Test Results

- Covered Conductor designed for 15kV
- Voltage Applied was 35kV
- Results: Covered conductor withstood contact with no failure



Test Subject	Time Duration	Empirical Average Current with Test Subject
Metallic Balloon	2 Hours	0.418A



Conclusion

- The simulation and test confirmed that the dielectric strength of the spacer cable system will withstand the maximum difference of potential at normal operating voltages of the circuit without breakdown or puncture

5. Safety Advantages

Safety

- In the case of a downed conductor, covered conductors will provide a safety advantage over bare wire.
- The covering on the covered conductor will reduce the charging current enough to result in, at most, a slight shock during human contact while contact with bare wire will result in electrocution.
- While evidence of a reduced charging current is available in multiple industry papers, SCE has sponsored a test with NEETRAC on covered conductor touch current to verify this data

Effects of Electrical Current

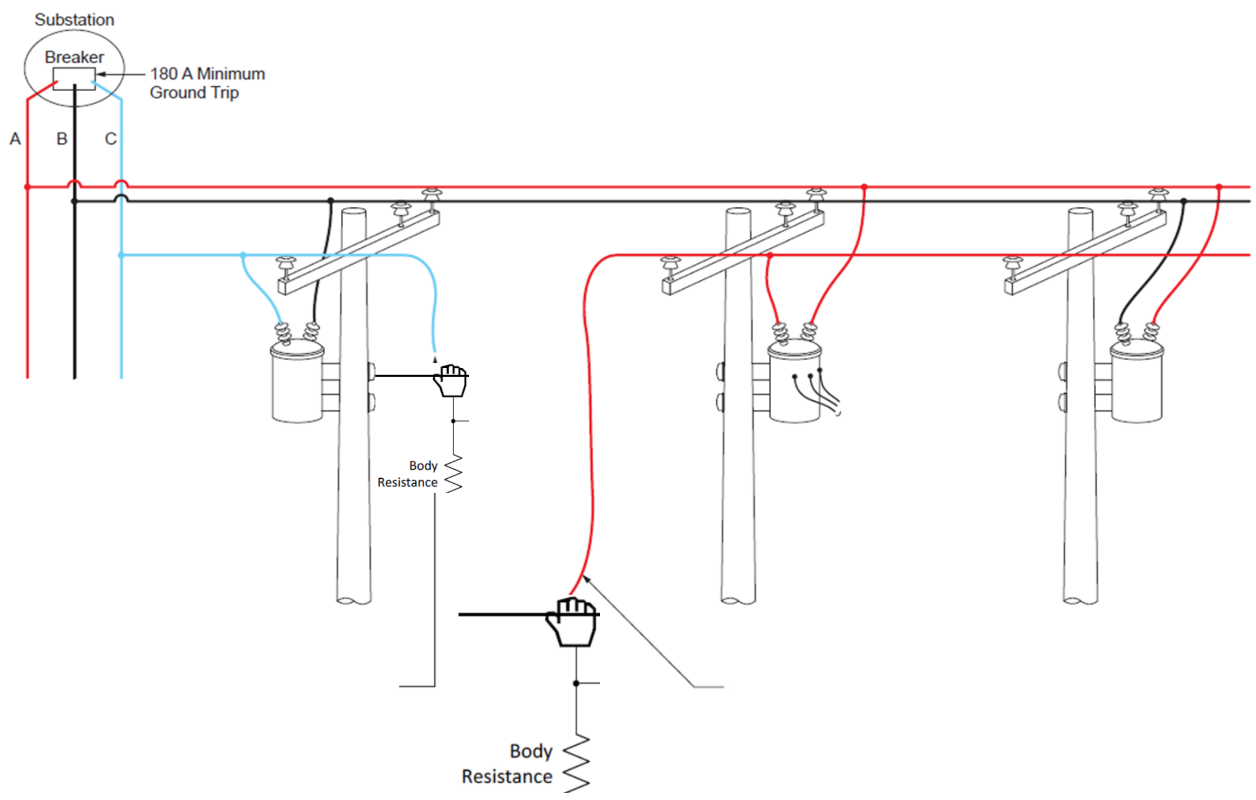
- Effects of Electrical Current on the Human Body

Current	Effect
Below 1 mA	Generally not Perceptible
1 mA	Faint Tingle
5 mA	Slight Shock; Not painful but disturbing. Average individual can let go
6-25 mA (women) **9-30 mA (men)**	Painful shock, loss of muscular control. The freezing current or "let-go" range. Individual cannot let go, but can be thrown away from the circuit if extensor muscles are stimulated
50-150 mA	Extreme pain, respiratory arrest (breathing stops), severe muscular contractions. Death is possible

NEETRAC Testing – Energized Downed Conductor

- The following are test cases of energized wire down scenarios that were simulated and empirically tested by NEETRAC
  - Person holding broken **covered conductor** on **line side**
  - Person holding broken **covered conductor** on **load side**
  - Person holding broken **bare conductor** on **line side**
  - Person holding broken **bare conductor** on **load side**

*Note that bare conductor test cases were not performed in the laboratory.



NEETRAC Testing

- Test Information:
  - Conductor: 1/0 Covered Conductor
  - Source: 12.447 kV
  - Test Results: Human contact current measured

	Covered Conductor		Bare Conductor
	Simulation Results (Theoretical Value)	Lab Test Results (Actual Values)	Simulation Results (Theoretical Value)
Line Side	0.220 mA	0.227 mA	5,300 mA
Load Side	0.218 mA	0.227 mA	34.2 mA

- Conclusion:
  - Covered Conductor Touch Current: Generally Not Perceptible
  - Bare Conductor Touch Current: Electrocution
  - Overall, covered conductors can potentially provide public safety benefits during wire down events

6. Understanding Wire Down

Understanding Wire Down

- Covered conductors will prevent wire downs from occurring by preventing contact related faults.
  - In SCE, over 50% of faults are contact related in HFRA.
- Energized wire downs can happen in both bare wire and covered conductor systems
  - The detection of a downed bare wire is not absolute. The main component that determines detection is the surface the downed wire makes contact with. Due to the surface, a high impedance fault may occur regardless of conductor type.
  - During a high impedance fault, the area of exposed conductor is greater in bare wire than in covered conductor. More exposed conductor may increase the chance of ignition.
  - Covered conductor systems will provide a public safety advantage over bare wire systems by reducing the touch current the public is exposed to.
- Alternative wire down detection systems that do not rely on fault current are in development. These systems will be effective for both covered conductor and bare wire systems.
  - SCE: Meter Alarming Downed Energized Conductor
  - SDG&E: Phasor Measurement Unit

7. Break Test

Covered Conductor Break Testing

- The purpose of this test is to visually observe the conductor and covering at the break point

1/0 ACSR (Conductor Breaking Strength: 4,160 lbs)				
Sample	Break (lbs)	Break Point	Length of Exposed Conductor (in.)	
1	5,230	Midspan	2.12	
2	5,230	Midspan	5.00	0.25
3	Results invalid due to conductor breaking at grip			

#2 Copper (Conductor Breaking Strength: 2,896 lbs)				
Sample	Break (lbs)	Break Point	Length of Exposed Conductor (in.)	
1	3,360	Midspan	0.31	0.15
2	3,380	Midspan	0.38	0.03
3	3,360	Midspan	0.50	0.25

Covered Conductor Break Testing

- ACSR Sample 1

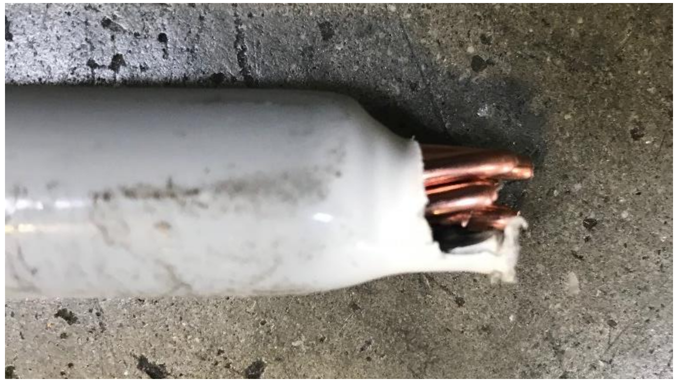
- ACSR Sample 2

Covered Conductor Break Testing

- Copper Sample 1


- Copper Sample 2


- Copper Sample 3




Covered Conductor Break Test

- Conclusion
  - The larger the area of conductor is exposed, the higher the probability of ignition and public safety risk
  - If broken, covered conductors pose reduced probability of ignition and public safety risk on exposed ends compared to bare conductors due to the covering

Chapter II
Expected Service Life

1. Expected Service Life

This section describes the life expectancy of covered conductors, the basis for the projection, and factors that influence service life.

Service Life

- SCE expects covered conductors to have a service life of **45 years**
- Conclusion of 45 years is based on
  - Manufacturer response
  - Historical Records
  - SCE experience with similar products

Manufacturer Survey

- Manufacturer consensus is that the covered conductor service life is expected to be 40 years minimum

Surveyed Questions	Supplier 1	Supplier 2	Supplier 3
1. What is the expected service life of the covering?	Minimum of 40 years, and probably 60 plus years	40 years	40 years
2. What is the expected service life of the conductor?	Useful service life in excess of 80 years	40 years	40 years
3. What is the expected service life of the covered conductor as a whole?	Excess of 67 years	40 years	40 years

Basis for Expected Service Life

- Advancement of compound technology and the upgrade of manufacturing equipment
- Known service life of XLPE is 40 years minimum
- Conformance to and successful passing of qualification tests ensures life expectancy
- Historical records with systems installed since 1951 are still in operation and performing as designed 67 years ago

Factors that Influence Service Life

- Conductor Temperature
  - Operating at extreme temperature is known to damage the conductor and/or covering
- Extreme contamination
- Severe UV exposure
- Installation methods and condition
- Type and Quality of Accessories

Qualification Testing

- SCE requires the following tests to ensure the longevity of the conductor
    - UV Testing
    - Environmental Stress Cracking
    - Track Resistance
    - Maximum Dielectric Constant
- Passing qualification tests ensures that the covered conductor deployed in SCE facilities meet industry standard and are high quality
- Passing ensures that the covering can perform as intended for a 45 year operating life

2. UV Resistance

This section describes the requirements of the UV resistance testing.

Sunlight (UV) Resistance Testing

- SCE requires conformance to ICEA S-121-733-2016 Sunlight Resistance (UV) Testing
- Testing will accurately predict, on an accelerated basis, the effect of sunlight
- UV testing will involve inducing property changes associated with the end use conditions, including the effects of sunlight, moisture, and heat. Testing requires specimens to be exposed to xenon-arc radiation and water-spray exposure.
- The exposure time is 720 hours with a radiation level of 0.35 Watt/meter. This radiation level was chosen based on the most extreme summer weather similar to the state of Florida, which is always equal to or greater in UV intensity than in Southern California.
- The covering is considered sunlight resistant if the original to aged tensile and elongation ratio 80% or greater after the 720 hours of exposure. Additionally, because the covering is grey, the amount of UV absorption will be limited.

Significance

- Testing ensures that the strength of the covering is still at least 80% of the original strength before accelerated UV exposure
- Overall, UV testing requirement ensures the longevity of the covering

3. Environmental Stress-Cracking

This section describes the requirements of Environmental Stress-Cracking Testing.

Definitions

- Stress-Crack – An external or internal rupture in a plastic caused by tensile stresses less than its short-time mechanical strength

Environmental Stress-Cracking Testing

- ICEA S-121-733-2016 does not require Environmental Stress-Cracking Resistance for 90ºC rated covered conductor because the covering material is inherently resistant to Environmental Stress-Cracking
- Environmental Stress-Cracking is the development of cracks in the material due to low tensile stress and environmental conditions. Under certain conditions of stress with the presence of contaminants like soaps, wetting agents, oils, and detergents, ethylene material may exhibit mechanical failure by cracking.

Significance

- Having a 90ºC Rated covered conductor means that the covering will be inherently resistant to cracking under conditions of stress and in the presence of contaminants

4. Track Resistance

This section describes the requirements of the track resistance testing.

Definitions

- Electrical Erosion – The progressive wearing away of electrical insulation by the action of electrical discharges
- Track – A partially conducting path of localized deterioration on the surface of an insulating material
- Tracking – The process that produces tracks as a result of the action of electrical discharges on or close to the insulation surface
- Tracking Resistance – A quantitative expression of the voltage and the time required to develop a track under specified conditions

Track Resistance Testing

- SCE requires conformance to ICEA S-121-733-2016 Track Resistant Testing
- Track resistance testing will evaluate the tracking and erosion resistance of the covering and its effects upon the insulation.
- During this test, the covering is exposed to a conducting liquid contaminant at an optimum rate, in a manner that allows continuous electrical discharge to be maintained.
- The effects are similar to those that may occur in service under the influence of dirt combined with moisture condensed from the atmosphere.
- Producing continuous surface discharge with controlled energy will mimic long-term exposure in the field in an accelerated time frame.
- For the sample to pass, the time to track one inch at 2.5 kV must be a minimum of 1000 minutes.

Significance

- Testing ensures that the covering is track resistance
- Track resistance properties will ensure insulation that electrical charges will not erode the insulation over time
- Overall, testing requirement ensures the longevity of the covering

5. Maximum Dielectric Constant

Definitions

- Dielectric Constant: a quantity measuring the ability of a substance to store electrical energy in an electric field
- Dielectric Strength: the maximum electric field that a pure material can withstand under ideal conditions without breaking down

Maximum Dielectric Constant

- The maximum dielectric constant must be 3.5, per ICEA standards
- The lower the dielectric constant, the higher the dielectric strength.

Significance

- Ensuring that the dielectric constant meets the requirements certifies that the insulation strength of the covering is acceptable and the covered conductor will perform as designed.

6. Production Testing

This section describes production testing requirements.

Production Testing

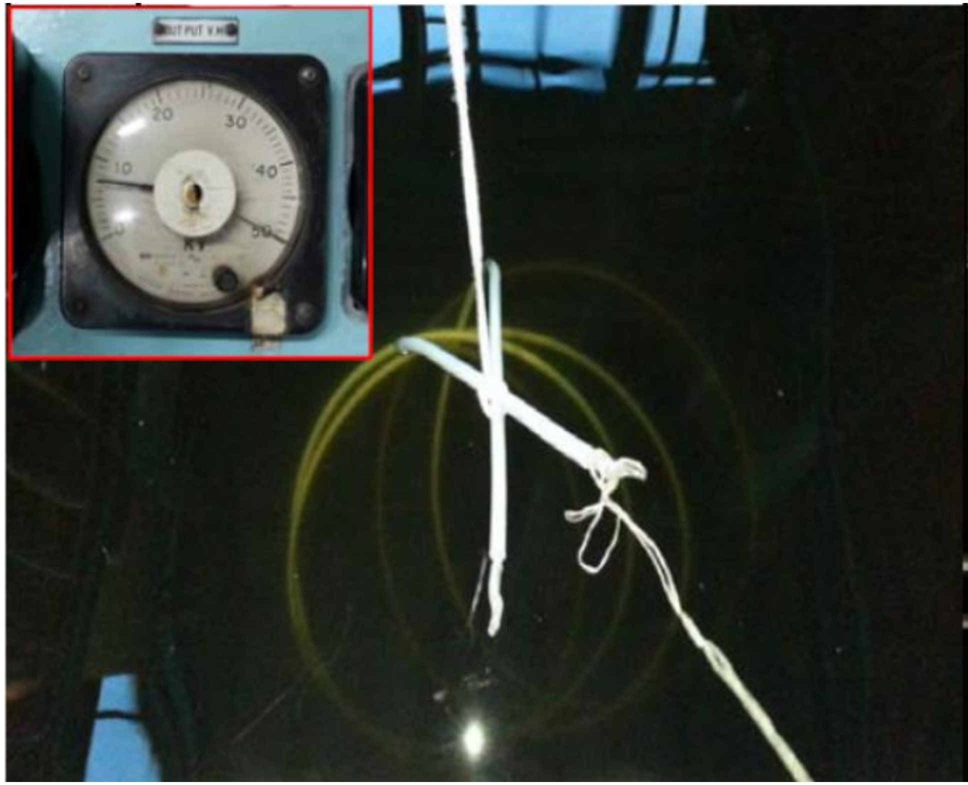
- SCE requires manufacturers to perform routine production testing
  - DC Resistance
    - The DC resistance on the conductor must not exceed 102% of the maximum allowable value
  - Unaged and Aged Tensile and Elongation
    - Tensile elongation is the stretching that a material undergoes. The point of rupture must be greater than 1800 psi for unaged samples. Samples are aged at 121°C for 168 hours. Aged samples must rupture at a minimum of 75% of the unaged value. This test validates the mechanical properties of the covering
  - Hot Creep
    - Hot creep tests validates that the covering is crosslinked, making it a thermoset. Thermosets can withstand higher temperatures and are less likely to deform at high temperatures.
  - Spark Test
    - Spark tests validates the integrity of the insulation. An electrical cloud is generated around the cable. Any pinholes or faults in the insulation will cause a grounding of the electrical field and this flow of current will register a defect in the insulation.
- Passing routine production tests ensures that the covered conductor deployed in SCE facilities meet industry standard and are high quality
- Passing ensures that the covering can perform as intended for a 45 year operating life

7. Short Circuit Test

Short Circuit Test

- The purpose of this test is to observe the effects of short circuit current on the covering.

Short Circuit Test



Withstand Test (AC 7.0 kV for 5 mins)
Meets ICEA T-27-581

Internal Dismantling Investigation

Short Circuit Test

Test Sample	Current (A)	Temperature (°F)	Time (Cycles)	Immersion Test Results (AC 7kV for 5 mins)
1	7,200	644	60	Pass
2	7,900	842	60	Pass
3	8,800	1,193	60	Pass
4*	10,000	1,904	60	Pass

*Outer surface slightly softened

Short Circuit Test

- Conclusion
  - The covering withstood extreme temperatures (maximum of 1,904°F) for a time duration similar to what the conductor will experience during a fault event with no damage to the conductor covering.

8. Flammability

Flammability of Covered Conductor

- Identified heat sources:
  1. Heating of the conductor (typically from fault current)
     - Performed short circuit current (10kA) test that exposed the covered conductor to 1,904°F for 60 cycles (worst case time duration based on relay tripping)
       - Covered conductor performed well with no damage to the covering
  2. From the fire below
     - Fire: 1,800°F, 3 minutes, 20 feet high flame
     - Testing illustrated the Covered Conductor can withstand 640°F (temperature at conductor) for 3 minutes
       - Heat source was 1,292°F and 5 inches away
     - SCE is conducting further tests to determine the temperature gradient at the conductor level and whether exceeding the temperature at the conductor will exceed 640°F
  3. Other equipment failure-caused fire
     - SCE has not experienced equipment failure-caused fire propagating through historical covered conductor installations
     - SCE has a long history of experience with underground cable and has not experienced equipment failure-caused fire propagating through underground cable
     - Korean Electric Power Company (KEPCO), with over 40 years of covered conductor experience, have not experienced equipment failure-caused fire propagating through the covered conductor.
- Conclusion: Covered conductors will not ignite due to heat sources identified above

9. Covered Conductor Failure Mode

This section articulates the possible failure modes and provides a high-level analysis how the these impact on Covered Conductor at SCE, and finally what SCE has done to address these failure modes

Known Failure Modes

- Covered conductor could have burn down if not adequately designed or installed
- The following known issues are addressed either by design criteria or installation guideline
  - Electrical tracking on surface of covers
  - Arc generated from lightning strikes
  - Aeolian (Wind-Induced) Vibration
  - Premature Insulation Breakdown

Mitigating Against Electrical Tracking on Surface of Covers

- Electrical tracking occurs when carbon pathways (tracks) formed on the surface of an insulating material which could lead to breakdown
- SCE will only procure CC that have completed extensive qualification testing to industry standards (UV Resistance, Environmental Cracking, and Track Resistance)
- Early material that suffer from tracking issues are crosslinked polyethylene with high carbon content for UV inhibiting purposes
  - SCE specified material using cross-linked high density polyethylene with little carbon black
- Early design of CC specify thin layers of insulation (less than 100 mils)
  - Covered conductor SCE will used has 150 mils of insulation

Arc Generated During Lightning Strikes

- During lightning strikes, an arc could form on the transition from covered to bare conductor, or where there are stripped or open point in the covered conductor
- Direct lightning strike on covered conductor would be more damaging than bare conductor because lightning moves more freely on bare conductors (to look for a path to earth)
- However, SCE is well prepared to mitigate this known issue for several reasons:
  1. SCE service territory is considered low lightning area
  2. Covered conductor is generally less “attractive” to lightning than bare conductor (insulating materials reduces electric field on the surface of covered conductor)
  3. SCE uses the most effective mitigation tool for lightning strikes
- Mitigating Lightning Failure
  1. Industry uses Arc Protection devices (APD’s), Power Arc Devices (PAD’s) and Lightning Arrestors (LA’s) for mitigating lightning strike failures
  2. Lightning Arrestor is the most well-built and effective device of all three
  3. SCE uses Lightning Arrestors and bolster the standards for covered conductor systems to be treated as high lightning area
  4. SCE’s high lightning standards require Lightning Arrestors to be installed in all equipment poles (all transformer sizes, capacitor, RAR, switch, voltage regulator, etc.)
  5. SCE standards requires Lightning Arrestors to be installed in covered conductor to underground transitions
  6. SCE will minimize stripping and removal of the covering
  7. SCE standards require stripped or uncovered portions will be covered (i.e. splice)

CONCLUSION: SCE is well positioned for protecting covered conductors from lightning because direct strikes on covered conductor are less likely at SCE, but if happens lightning strikes be mitigated by Lightning Arrestors, i.e. direct to ground instead of stuck on one covered location, or covered to bare transition or flash over to other phases.

Aeolian (Wind Induced) Vibration

- Wind induced vibration of conductors could lead to fatigue failure of the conductor (similar to bending a piece of wire back and forward until it break)
- High conductor tensions lead to Aeolian vibration issues
- Mitigating Aeolian Vibration
  - SCE developed proper sag and tension values for covered conductor
  - SCE's tension limits are in line with Northeast Utilities that have an 80% covered conductor system.
  - The Northeast utilities have not experienced problems due to Aeolian vibration

Premature Insulation Breakdown

- Wear and tear could lead to premature insulation breakdown
  - Insulation breakdown will equate effectiveness of covered conductor to bare
  - Result from improper installation or constant abrasion from vegetation
- Mitigating premature insulation breakdown
  - Outer covering is a high density material, and is resistant to incidental abrasion
  - Discussion with other utilities indicated that older covered conductor design performed as intended even after 50 years
  - Construction standard requires care during installation and handling of the covered conductor

Learning from Past Experience

- SCE have performed literature research, talked to industry experts, visited utilities and suppliers, and employed consultants to inform the design and installation of covered conductor to withstand early known issues
- Based on past performance in various utilities and the robustness of the current covered conductor design, Engineering fully expect the covered conductor to perform for at least 45 years without issues

Chapter III
Industry Benchmarking and Research

1. Research

Global Research

- Global information was gathered from covered conductor research literature as well as government and utility publications.

Global Research – Australia (Historical Installations)

- Covered Conductor has been used in Australia for over 50 years
- Early installations experienced the following problems:
  - Initial coverings of PVS, HDPE, and nylon gave very limited lifetimes and suffered surface degradation.
  - Initial installations were subject to failure due to lightning damage
- In the late 1980s, Australia reconsidered Covered Conductor for safety considerations (human and wildlife), conductor clashing, tree problems, and bushfire mitigation.
  - However, within 2 years of installation, it was found that the covered conductor was incapable of handling anything more than momentary contact
  - Other problems include severe RF emissions and tracking
- In the mid 2000s research for the Australian Strategic Technology Program illustrated that technological advancements and solutions to historical issues regarding covered conductors exist, which may allow for a widespread adoption of covered conductors in Australia

Global Research - Australia

- In 2009, the Victorian Bushfires Royal Commission (VBRC), which was established in 2009 by the government after the devastating Black Saturday bushfires, recommended the following:
  - The progressive replacement of all SWER (single-wire earth return) power lines in Victoria with aerial bundled cable, underground cabling or other technology that delivers greatly reduced bushfire risk. The replacement program should be completed in the areas of highest bushfire risk within 10 years and should continue in areas of lower bushfire risk as the lines reach the end of their engineering lives
  - The progressive replacement of all 22-kilovolt distribution feeders with aerial bundled cable, underground cabling or other technology that delivers greatly reduced bushfire risk as the feeders reach the end of their engineering lives. Priority should be given to distribution feeders in the areas of highest bushfire risk.
- Progress of VBRC recommendation implementation:
  - 2010 – Established a Bushfire Powerline Safety Taskforce (BPST) to recommend to the Victorian Government how to maximize the value to Victorians from the VBRC recommendations.
  - 2011 – The Bushfire Powerline Safety Taskforce recommended the following:
    - The BPST recommended to target SWER and 22kV powerlines in the next 10 years
    - The BPST recommended that any new powerlines built in areas targeted for replacement should also be built with underground or covered conductor
    - Estimated a 90% reduction in the likelihood of a bushfire starting by installing covered conductors
    - Recommendations were accepted by the Minster for Energy and Resources on December 29, 2011
    - AUS $750 million Powerline Bushfire Safety program was announced by the Victorian Government
  - 2012 – Areas of highest bushfire risk for purposes of asset installation were identified and a detailed forward works program was developed
  - 2013 – A brief focusing on the first five years of the program, described in more detail the complexities of delivering the substantial set of reforms and provided concise project planning, management, and delivery structure.
  - 2014 – Installation of first replacement powerline in high bushfire risk areas
  - **2016 – Amendments were made to the Electricity Safety (Bushfire Mitigation) Regulations which specify the use of covered conductors or undergrounding for any new or rebuilt circuits in high bushfire risk areas**
    - **The Victorian Government's Powerline Replacement Fund makes available up to $200 million to electrical distribution businesses and private land owners to replace bare wire powerlines**

Global Research – Australia

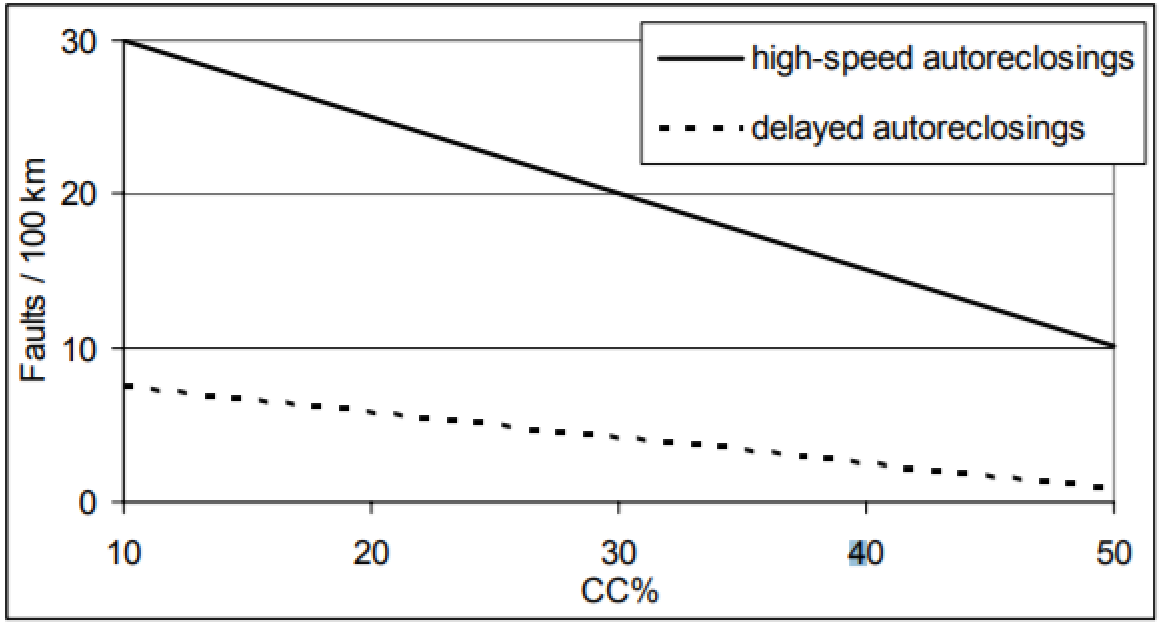
- Utility Implementations of VBRC Recommendations
  - Ausnet
    - Victorian utilities to use either insulated or covered conductor for any planned conductor replacement of more than 4 spans of 1kV-22kV line (within codified areas)
    - For AusNet, the codified areas included approximately 1,000 miles of bare wire, medium voltage powerlines. **They began replacing line in this area in 2014 relying on an established $200M Powerline Replacement Fund (PRF)**
    - AusNet is progressively replacing the remaining bare wire in codified areas outside of PRF activities because of the cost associated with insulated/covered conductors
    - **Construction of any new medium voltage electric line that is part of the supply network must use insulated cable or covered conductor**
  - Powercor
    - Per their 2016 Bushfire Mitigation Plan, Powercor is implementing underground cable/overhead covered conductor when construction either 22kV, single wire earth return (SWER) or low voltage assets for all new construction and the same Electrical Safety (Bushfire Mitigation) Regulations listed for AusNet reconductoring activities
- Utilities outside of Victoria
  - Energy Queensland
    - 2017 Summer Preparedness Plans target installation of covered conductor in bushfire risk areas.
  - Essential Energy
    - Bushfire Risk Management Plan (Issue 13, 2017) was provided to meet the objectives and requirements of the NSW Electricity Supply (Safety and Network) Regulation 2014, which includes a provision for the review of equipment types or construction methods known in their operation or design to have bush fire ignition potential and a mitigation strategy in relation to their use
    - Plan calls for use of underground cable and covered conductor on overhead primary, promoting underground or insulated low voltage lines in rural areas, and identifying at-risk private low voltage lines on customer properties and undergrounding or replacing with CCT

Global Research - Europe

- United Kingdom
  - The UK started installing covered conductors in 1994
  - The typical close spacing and compact construction prompted the first use of covered conductors in the UK
  - As of 2005, UK has installed 9,300 circuit miles of covered conductor
- Sweden
  - Covered Conductor was first introduced in Sweden in 1984.
  - First installation was in a snowy and high wind area to reduce faults due to snow-laden branches resting on the line and wire slapping
  - As of 2005, Sweden installed approximately 2,500 miles of covered conductor
  - 60% of new construction and refurbishment schemes use covered conductor
- Slovenia
  - First CC line was built in December 1993
  - By 2003, CC lines presented about 8% of all medium voltage overhead lines

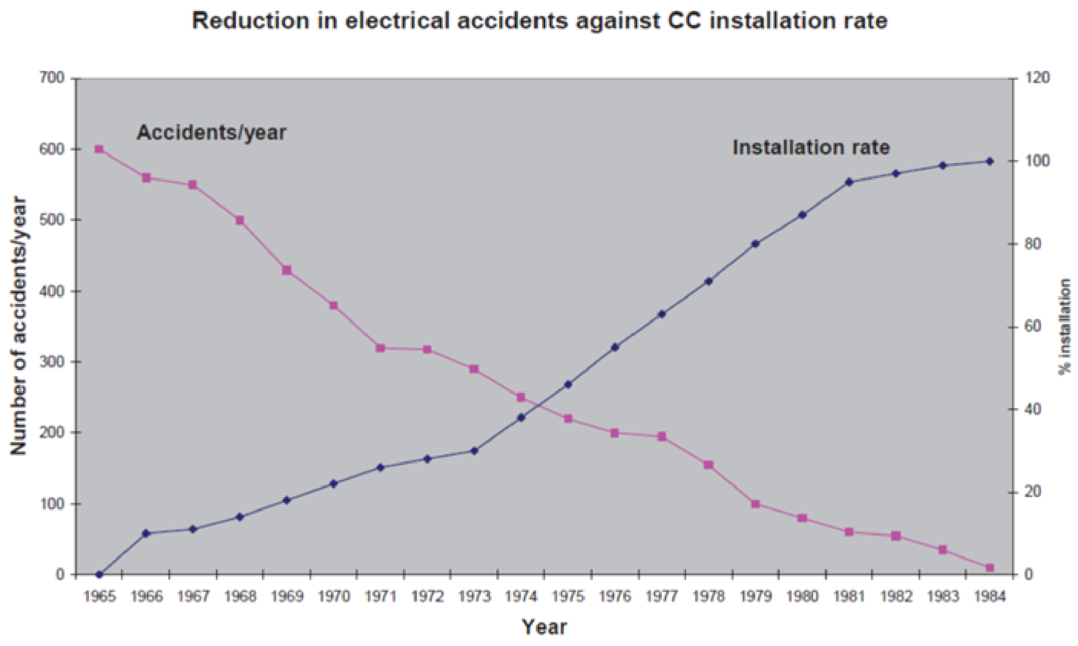
Global Research - Europe

- Finland
  - Finland installed the first installations of covered conductors in Europe.
  - Main impetus for research into covered conductors in the 1970s was the reduction of forest fires caused by trees falling on bare overhead lines.
  - As of 2005, Finland installed approximately 3,100 miles of covered conductor.
  - 60% of new construction and refurbishment schemes use covered conductor.
  - Number of permanent faults in CC lines is about 20% of those in bare conductor medium voltage lines
  - Number of high-speed automatic reclosings reduces to one third when the percentage of covered conductor lines is increased from 10% to 50%



Global Research - Asia

- Japan
  - Started using covered conductors in 1965
  - Driving force behind CC installation is to reduce the number of accidents and fatalities due to bare OH lines and improve reliability



2. Benchmarking

Benchmarking

- SCE benchmarked with a number of utilities abroad and in the United States
- Utilities SCE benchmarked with include:
  - Seattle City Light (Washington)
  - Puget Sound Energy (Washington)
  - Con Edison (New York)
  - Orange and Rockland Utilities (New York)
  - Liberty Utilities (New Hampshire)
  - Groveland Light (Massachusetts)
  - Holyoke (Massachusetts)
  - Middleton (Massachusetts)
  - Ausnet (Victoria, Australia)
  - Korea Electric Power Company - KEPCO (South Korea)
  - National Grid (Massachusetts)
  - Eversource (New Hampshire)
  - United Power Colorado

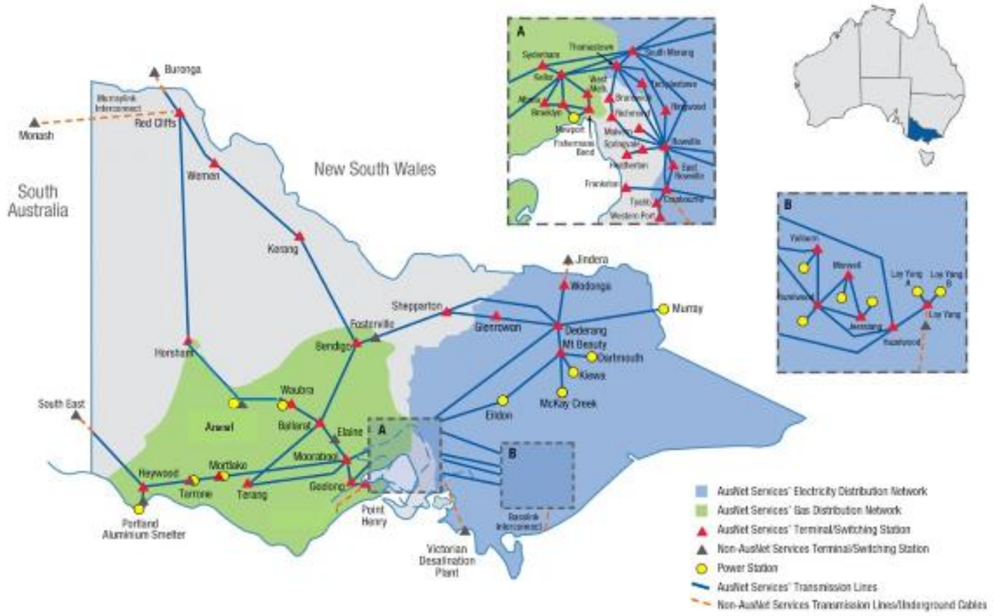
Utility Benchmark Questionnaire

- Sent out survey questionnaire to utilities to learn about covered conductor standards, application and performance:
  - Seattle City Light (Washington)
  - Puget Sound Energy (Washington)
  - Con Edison (New York)
  - Orange and Rockland Utilities (New York)
- Learned about downed wires with covered conductor
  - In Early 1980s, Con Ed experienced plenty of burn downs
    - Failures were at dead ends and equipment leads
    - Failures were at bare to covered transitions
  - Orange and Rockland found that protective relays will trip during a burn down
- Failure modes of covered conductor
  - Nicked conductor during stripping
  - Prolonged incidental contact (months)
- Cable type and Size
  - Seattle City Light and Puget Sound: 125 mils HDPE
  - Con Edison: 175 mils EPR
  - Orange and Rockland: 40-80 mils XLPE
- Voltage
  - Seattle City Light: 7.2 kV
  - Con Edison:
    - 27 kV – Mostly CC
    - 4-14 kV – CC

Round Table Benchmark with Northeast Utilities

- Conducted an in-person discussion on covered conductor experience with the Northeast utilities:
  - Hendrix (manufacturer), Liberty Utilities (New Hampshire), Groveland Light (Massachusetts), Holyoke (Massachusetts), Middleton (Massachusetts).
  - Past standards engineer of Eversource attended as well
- Covered Conductor Systems
  - New England overall is approximately 80% Covered Conductor and 20% Bare
- End of life
  - Covered conductor still looks and performs the same after 50+ years of service
- Issues
  - Manufacturing problems due to ring cuts was experienced in the late 70s before cleanrooms
  - Corona is main failure mode (phase to ground through tree), but it takes years to fail
  - None has experienced Aeolian vibration issues
  - None has encountered water ingress
- Lightning
  - Burn down happens at stripped portion
  - Add lightning arrestors at equipment, transitions to bare, and dead-ends
  - Had enough incidents to decide to install lightning arresters at end of line
  - All advise not to install lightning arresters at every 1000 ft. Avoid stripping as much as possible.

Ausnet

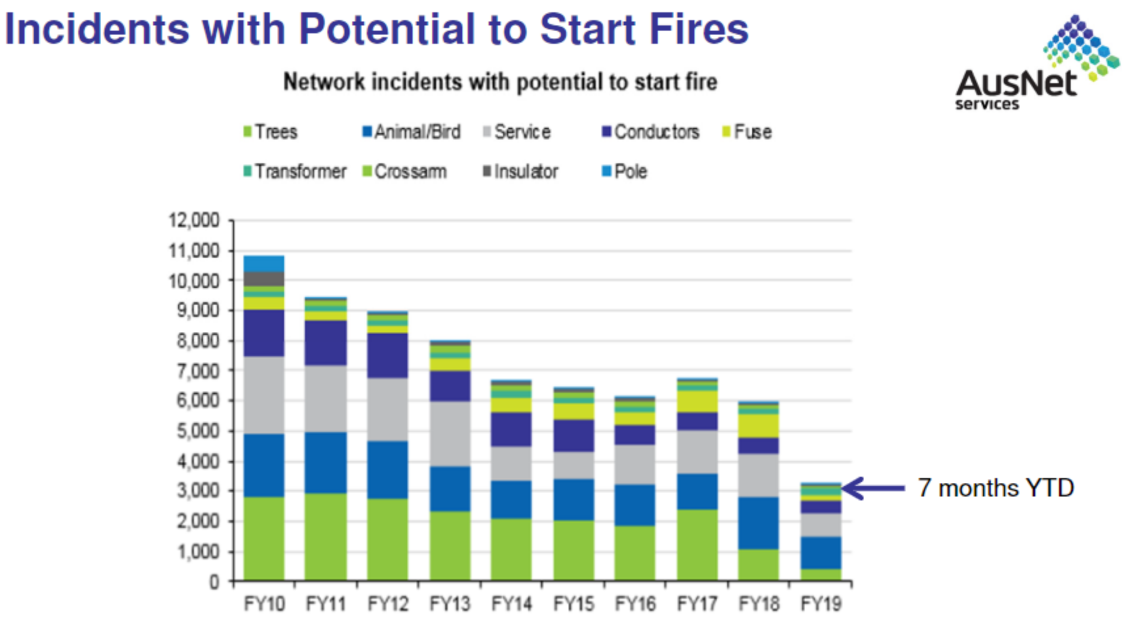


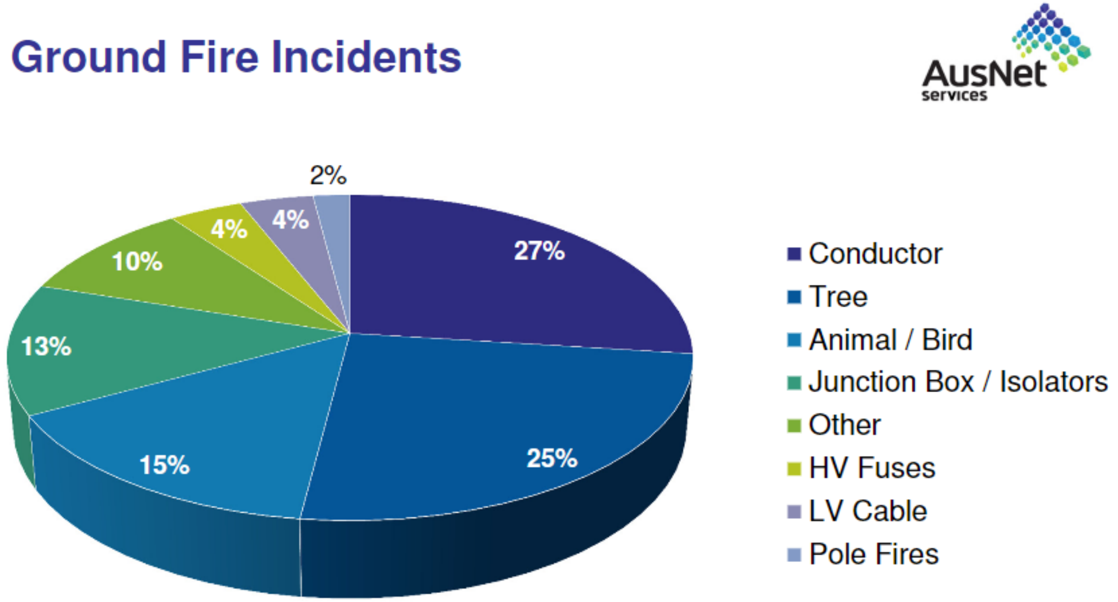
Electricity Transmission
- 6,600km of transmission lines
- 13,000 towers

Electricity distribution
- 52,263km of electricity distribution network
- 370,000 poles
- 722,000 customers

Gas distribution
- 11,400km of gas distribution network
- 692,000 customers

Ausnet – Fire Incidents

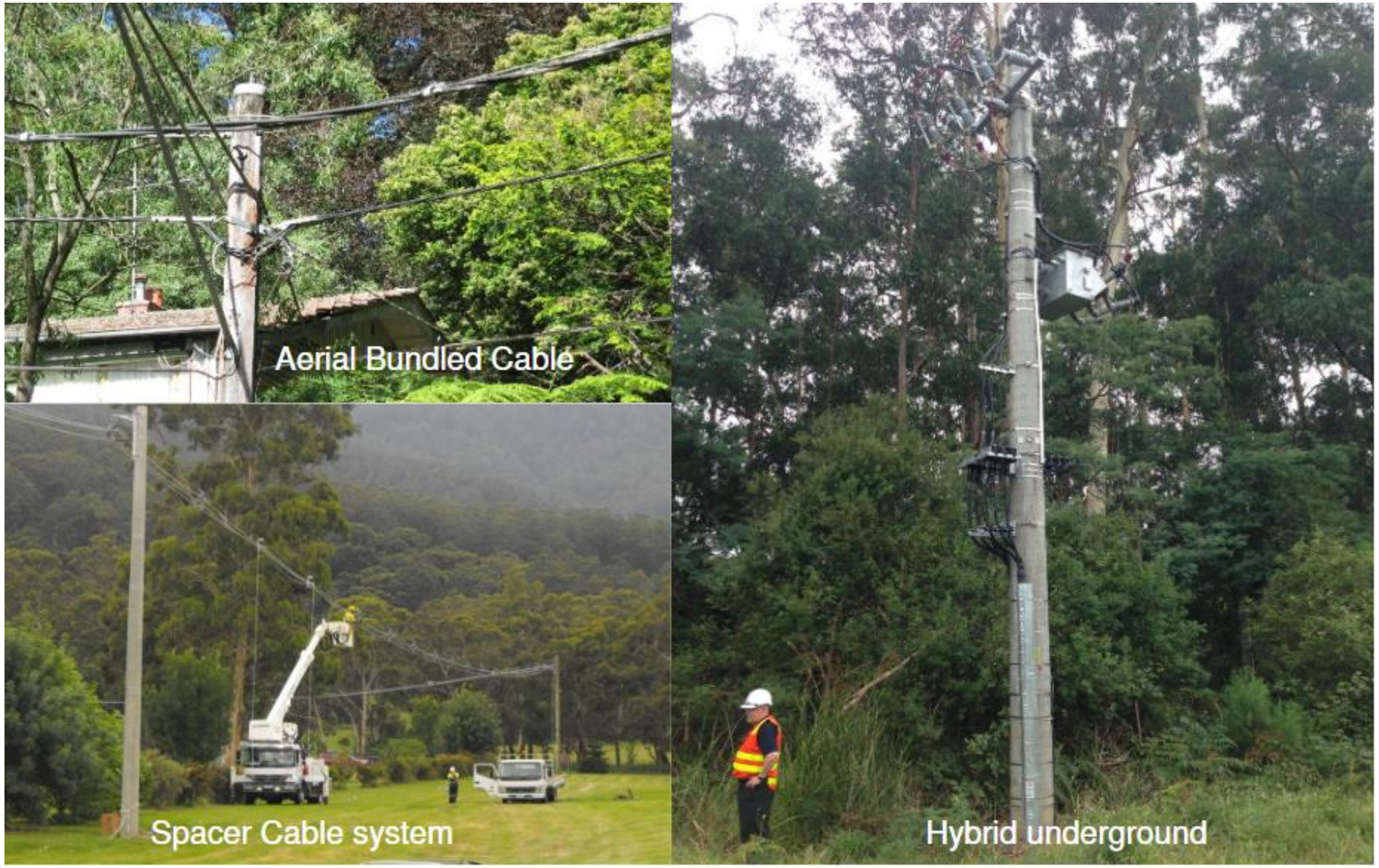




Ausnet – Wildfire Mitigation Programs

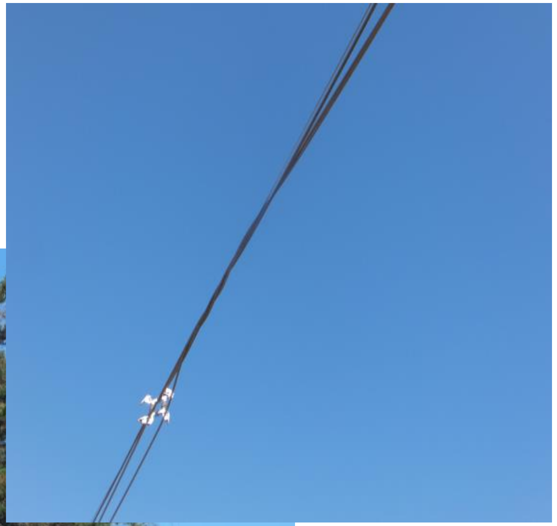
- Conductor replacement
- Service cable replacement
- Crossarm replacement – Standard Steel
- Insulator Replacement
- Vegetation Management
- Expulsion Drop Out fuse replacement with Boric Acid
- SWER OCRs replaced with remote controlled ACRs
- Bird/Animal proofing of complex HV structures
- High resolution digital photography inspection

Ausnet – Conductor Replacement



Ausnet – Covered Conductor Ignition Mitigation

- Event
  - A cypress tree blew onto covered conductor during a storm on December 2015
  - The storm knocked off the spacers, causing the covered conductor to get tangled up (phase-to-phase contact)
    - Ausnet personnel responded three days after the storm
- Outcome
  - Line was de-energized to remove tree and untangle the conductors to reinstall the spacers
  - No Fault
    - Covered Conductor covering prevented a phase-to-phase and phase-to-ground fault
  - No Wire Down
    - The spacer cable system withstood the tree's weight, preventing the conductor from severing
  - No Ignition
    - Covered Conductor prevented a fault that could lead to possible ignition
    - Ignition due to wire down was prevented due to covered conductor not severing upon the weight of the tree



Korea Electric Power Corporation (KEPCO) Visit

- KEPCO Overview
  - Transmission - 21,004 circuit miles, UG = 11.8%
  - Substations - 834
  - Distribution - 297,094 circuit miles, UG = 17.7%
  - SAIDI - 9.61
- Covered Conductor Use and History
  - 100% Covered Conductor System (Bare Neutrals)
  - Covered Conductor used since 1978 (40 years)
  - Reason for Covered Conductor Use is Public Safety and CFO Prevention

KEPCO Distribution Wire History

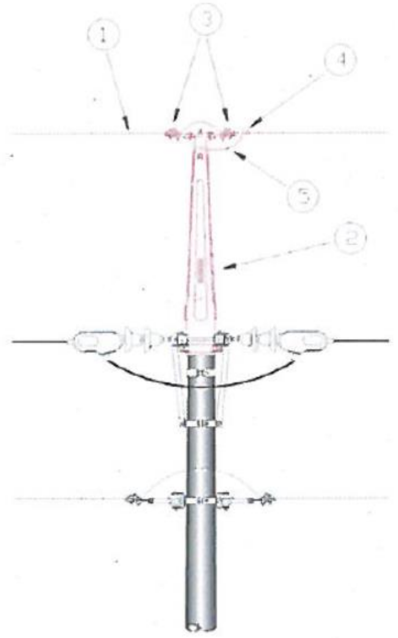
Before 1960s
- Used Cotton Insulated Wire

1962
- Used Bare Wire

1965
- Used ACSR

1978
- Used Covered Wire urban areas of large cities to prevent accidents caused by bare wire

KEPCO – Mitigating Known Issues



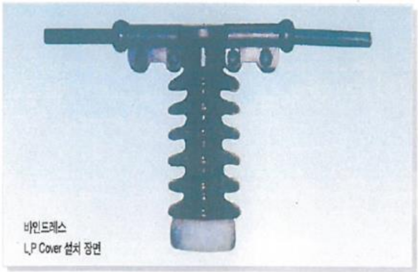
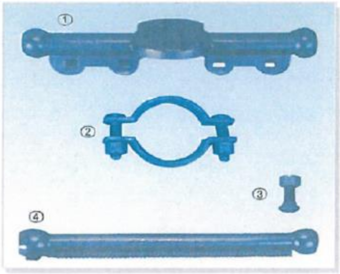
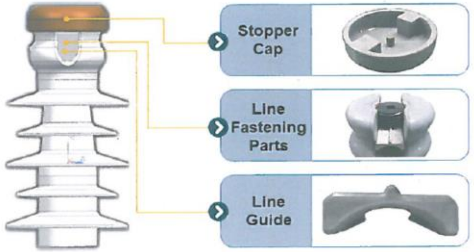
- Lightning Protection
  - Overhead grounding wire
    - Placed on top of pole
    - Block both direct lightning and induced lightning
    - Earth of OH grounding wire is connected to crossarm, which is connected to the neutral line.
    - Grounding rod is earthed every 200m and grounding resistance is kept below 25Ω
  - Arcing horn
    - Installed on the straight line (LP insulator) of the distribution line
      - Install on the line where fault caused by lightning has occurred
      - Install one for every two spans and install lightning arrester for protection of equipment in the section where arching horn is installed

KEPCO – Mitigating Known Issues

- Lightning Protection (Continued)
  - Lightning arresters
    - Lightning arresters to be installed in the following locations
      1. Device and Special Places
         a) The connection point from the substation bus line to the distribution line
         b) Connection point between the aerial line and underground line
         c) Front and rear ends of Recloser, Sectionalizer, Breaker, and Switchgear
         d) Each phase of the front side of the condenser
         e) Primary part of the transformer. However, it can be omitted when the lightning arrester is installed within 656 ft
      2. Distribution Line
         a) Branch, Terminal, Dead end pole
            - However, lightning arrester can be omitted at the following places
              i. Urban areas where high-rise buildings (more than 65 ft in height)
              ii. If lightning arrester is installed within 410 ft
         b) For other places, install every 1640 ft or less, unless a lightning arrester is installed within 656 ft
         c) Connection point between covered and bare wire
         d) The point where wire size changes
         e) The starting and ending points of the overhead ground wire

KEPCO – Mitigating Known Issues

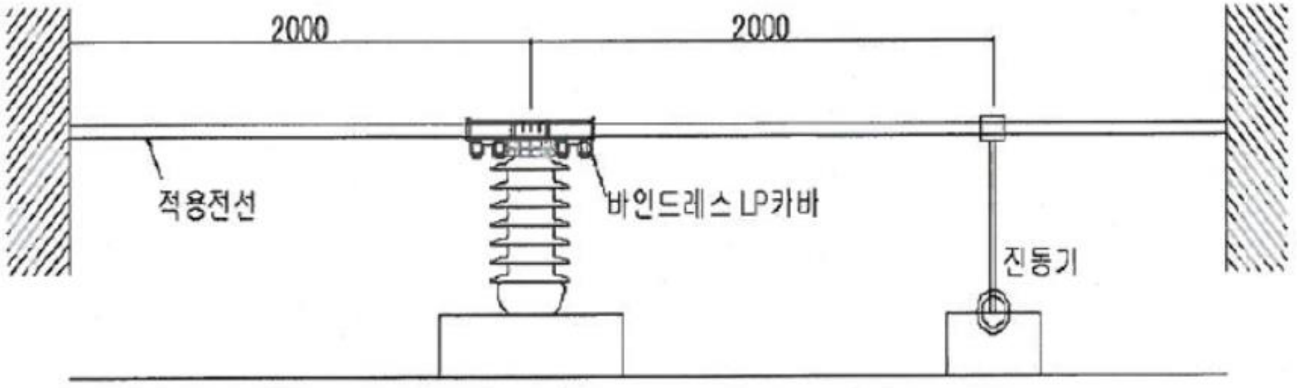
- Aeolian Vibration
  - For prevention KEPCO uses the following insulators

Insulator	Image
Bind Wire	
Bindless LP Cover	 
Bindless LP Insulator	

KEPCO – Mitigating Known Issues

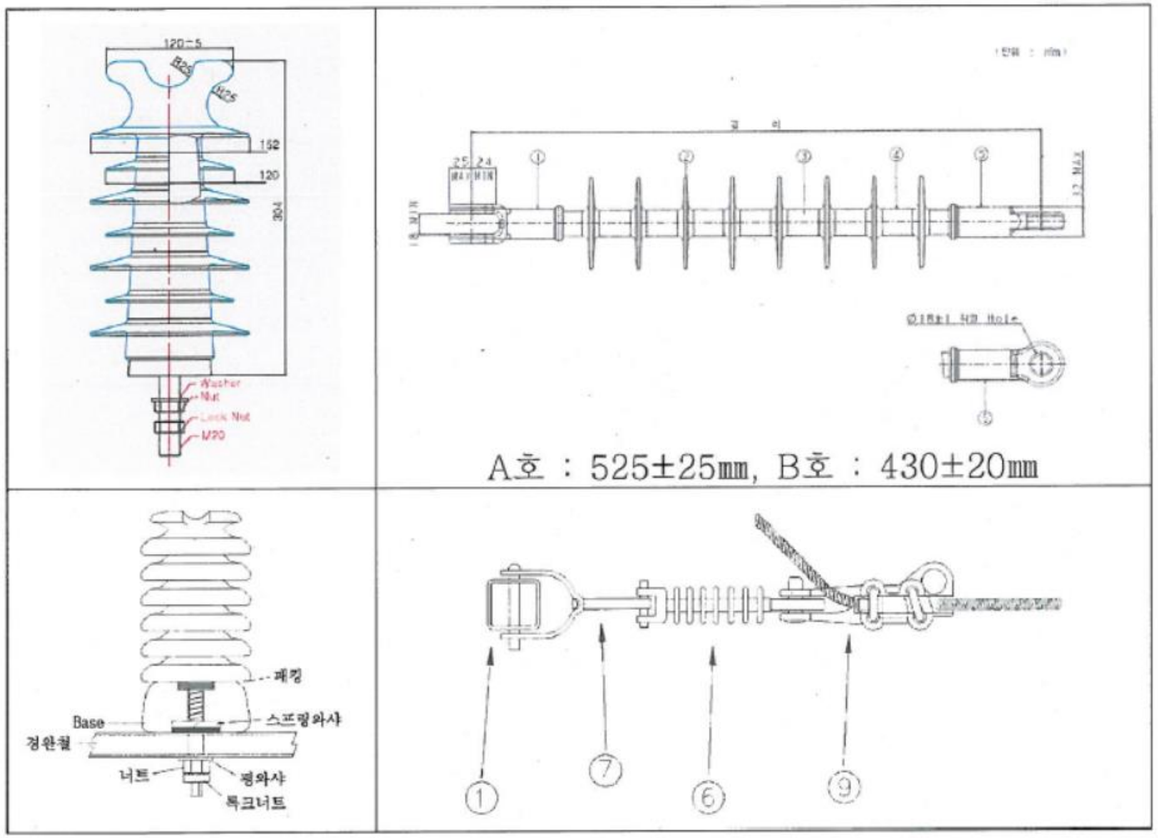
- Aeolian Vibration (Continued)
  - Perform Vibration Testing on Insulators
  - Cable, insulator and LP cover should not be damaged

Vibration Speed (times/minute)	Amplitude (in)	Vibration Direction	Vibration Frequency
1,200	0.24	Vertical	1 million



KEPCO – Mitigating Known Issues

- Insulators
  - Use Polymer Line-post insulator , polymer suspension insulator



KEPCO – Mitigating Known Issues

- Water Blocking
  - Conductors are filled with waterproof semi-conductive compound to prevent water from penetrating easily into the interior of the conductor
- Wire Down Detection
  - When fault current is detected, it is blocked through the protection coordination with the recloser
  - Monitored and controlled through the Distribution Automation System (DAS)
  - Detect 95% of downed wires
  - It is more difficult to detect fault with covered conductor compared to bare

KEPCO – Installation and Construction

- Construction Type
  - KEPCO uses cross-arm configuration
  - Testing spacer but commented that did not go with spacer system due to being 1.5 to 1.7 times more expensive
- Cover Everything
  - Dead-end clamp cover
  - Branch sleeve
  - Compression sleeve
  - Insulated Connector
    - For ground wire

KEPCO – Installation and Construction

- ABC to Covered Conductor Transition

KEPCO – Installation and Construction

- Equipment Connection

KEPCO – Installation and Construction

- Double Dead-end

KEPCO – Operation and Maintenance

- Inspection Standard

구 분	기 준			
Regular inspection	overhead	High-voltage	Downtown	Once every 6 Months
			Residential area	Once every 1 year
			other	Once every 2 years
		Low-voltage		Once every 2 years
	underground	More than once a quarter		
	national important facilities	Once a month		
Safety inspection	More than once a month			

KEPCO – Operation and Maintenance

- Wire Inspection Criteria
  - Corrosion of wires and connections
  - Damage to the wires in the bind area
  - Confirm state of bind relaxation and dropout
  - Whether wire is cut or damaged
  - Whether or not the support point is defective (clamp)
- Action Type
  - Immediate Action
  - Action within 1 month
  - Action within 2 months

KEPCO – Operation and Maintenance

- Types of Facility Diagnosis
  - High Frequency Diagnosis
    - Measure RF noise caused by deterioration of equipment by using high frequency equipment
  - Ultrasound Diagnosis
    - Detect PD by converting ultrasound of discharge pulse caused by defective equipment into audible sound
  - Thermal Imaging
    - Measure overheat point of equipment with thermal camera
  - Optical Equipment Diagnosis
    - Use high magnification optical camera to observe appearance and condition of the distribution structures and lines
  - Precise Visual Inspection
    - Check condition of distribution facility through visual inspection and measuring the live wire on the pole

National Grid Benchmark Summary

- SCE visited National Grid (Massachusetts) to conduct an in-person discussion about covered conductor
- Covered conductor open crossarm construction vs. spacer cable
  - 80% Open crossarm construction and 20% Spacer cable construction
  - Construction time for spacer cable construction is 1.5 times more than open crossarm construction
  - Bare wire is used when no trees are present
- Issues encountered
  - Most common failure is burndowns at the stripped portions
    - Cover stripped sections with gelwrap to prevent failure
  - Wire down trouble in beginning
  - Experienced problems when mixing suppliers for spacer system
- Four most important factors for success and longevity of Spacer Cable
  - Proper design and installation of guying
  - Proper messenger and phase conductor installation
  - Proper application and installation of surge protection
  - Proper application and installation of grounding
- Other information
  - Construction audits are performed to ensure installation is correct
    - Work with an audit checklist

Eversource Energy Benchmark Summary

- SCE visited Eversource (New Hampshire) to conduct an in-person discussion about covered conductor
- Covered Conductor Strategy
  - Built spacer systems in the 1960s, but it was low usage
  - For reliability purposes, Eversource started to deploy covered conductor system wide in 2015
    - $900k/year spend on covered conductor/spacer cable and do not see this stopping
    - $145 million capital program in New Hampshire
    - Before 2015, less than 5% of their system was CC. Now, increased to less than 10%
    - Bulk of deployment is spacer system
      - Installation distribution is 99% spacer cable and 1% open crossarm configuration
      - Chose spacer system to account for future. In 10 years, there may be trees that grow nearby
- Reliability Improvements
  - Reliability increased but driven by multiple factors
    - Spacer system
    - Building circuit ties
    - Added SCADA units (saved 30 mins under SCADA)
    - Class 2 poles

Eversource Energy Benchmark Summary(Continued)

- System Design
  - Poles:
    - Use steel poles
      - Wood poles had woodpecker issue
    - Use composite pole in roadside circuits where they experience guying problems
    - Standardized to class 2 poles (~2 years ago)
  - Crossarm: Started using composite crossarm 3 years ago
  - Covered conductor
    - Sizes 1/0 ACSR and 477 AAC
    - Do not permanently cover taps
    - Do not cover connections
    - Do not use IPCs
  - Lightning Arresters in CC System
    - Used every time the spacer system is opened up
    - All equipment
      - If no equipment, 4 per mile
      - Bare to covered transition points
    - Have not experienced burn down due to lightning
- Construction, Maintenance, and Cost
  - For new installation time: 1.25x more for spacer versus bare
  - For restoration time: 2x more for spacer versus bare
  - General engineering estimate is $0.5 million/mile at 35kV
    - Change out almost every pole since spacer drives taller poles

Eversource Spacer System Pictures

United Power Benchmark

- SCE visited United Power (Colorado) to benchmark and learn about their covered conductor use for wildfire mitigation
- United Power has two distinct terrains – Plans and Mountains
- United power installed covered conductor to address wildfire risk in Mountain Terrain area
  - Local jurisdiction does not allow underground cable installation
  - Home owners do not allow cutting trees
- United Power has deployed 7 circuit miles of Spacer Cable
  - 3 circuit miles of single phase spacer cable installation in 2015
  - 4 circuit miles of three phase spacer cable installation in 2016
- Advantages
  - Mitigates wildfire
  - Improves reliability
- Covered Conductor Success Story
  - During a high wind event, a tree fell into the spacer cable line
    - Contact with line lasted for a few days
    - Outcome:
      - No outage
      - No wire down
      - No ignition
  - During tree trimming, a tree fell into the line, breaking several spacer brackets midspan
    - Tree caused the covered conductor to wrap around the bare messenger (neutral).
    - Outcome
      - No outage
      - No Wire down
      - No ignition

3. Industry Surveys

Background

- SCE requested members of the following groups to participate in a survey about covered conductors
  - Edison Electrical Institute (EEI)
  - Western Underground Committee (WUC)
  - The Association of Edison Illuminating Companies (AEIC)
- A total of 36 utilities participated.

Summary

- Bare wire is the standard.
  - On average bare wire makes up 88% of a utility's distribution system
- 28% of participants indicated that they use covered conductors on primary distribution lines.
- 33% of participants indicated that they historically used covered conductors, but no longer use them on new installations
- Most utilities indicated that covered conductor is used to prevent vegetation contact
- Most utilities indicated that the benefit of using covered conductor is less contact related faults

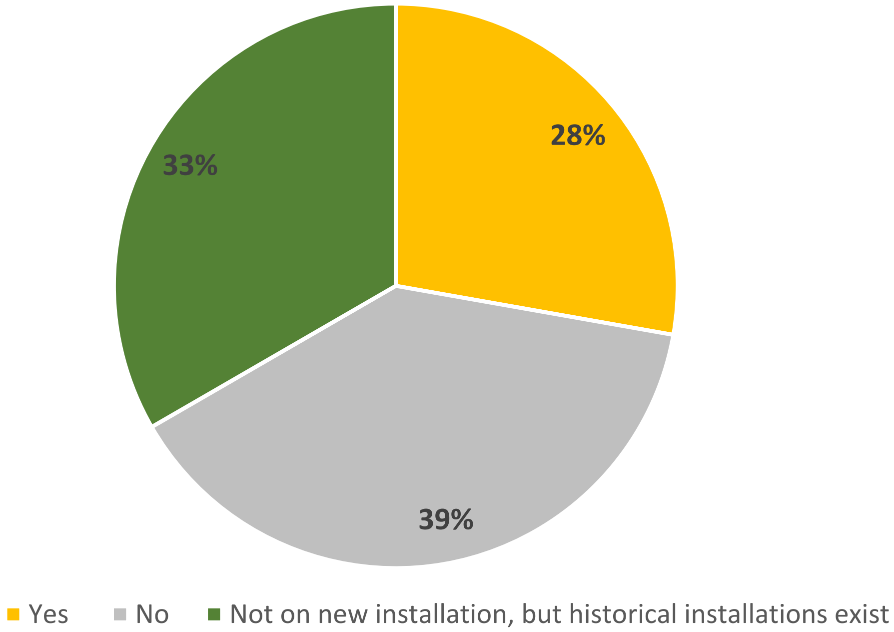
List of Participants

1	AES
2	Alliant Energy
3	Ameren
4	American Electric Power
5	Anonymous Participant
6	CenterPoint Energy
7	City of Banning
8	City of Lodi
9	City of Mesa Energy Resources
10	City of Richland, WA
11	City of Roseville
12	Con Edison
13	Dominion Energy
14	DTE Energy
15	Duke
16	FirstEnergy
17	Florida Power & Light
18	Idaho Power
19	Kansas City Power and Light

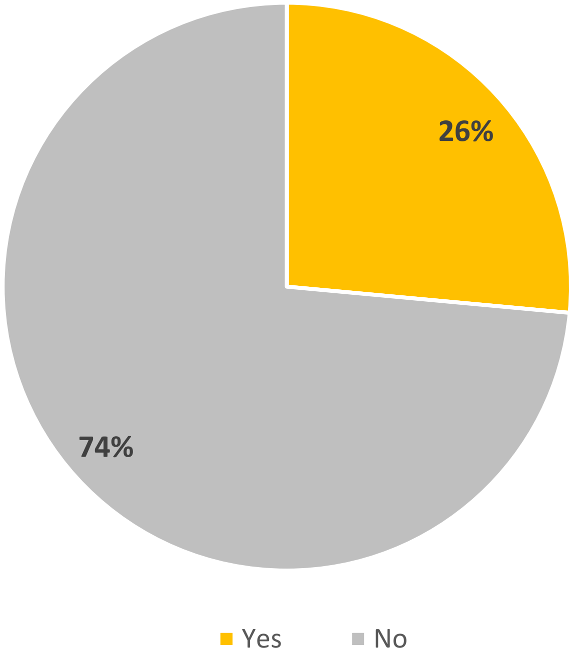
20	LADWP
21	LG&E and KU Energy
22	Midwest Energy, Inc.
23	National Grid
24	Northern Indiana Public Service Co.
25	Northwestern Energy
26	Oklahoma Gas & Electric
27	Oncor Electric Delivery
28	Orange & Rockland
29	Puget Sound Energy
30	Sacramento Municipality Utility Distrct
31	Salt River Project
32	Snohomish PUD
33	Southern Company
34	Tampa Electric
35	Tucson Electric Power
36	Westar Energy

Covered Conductor Usage

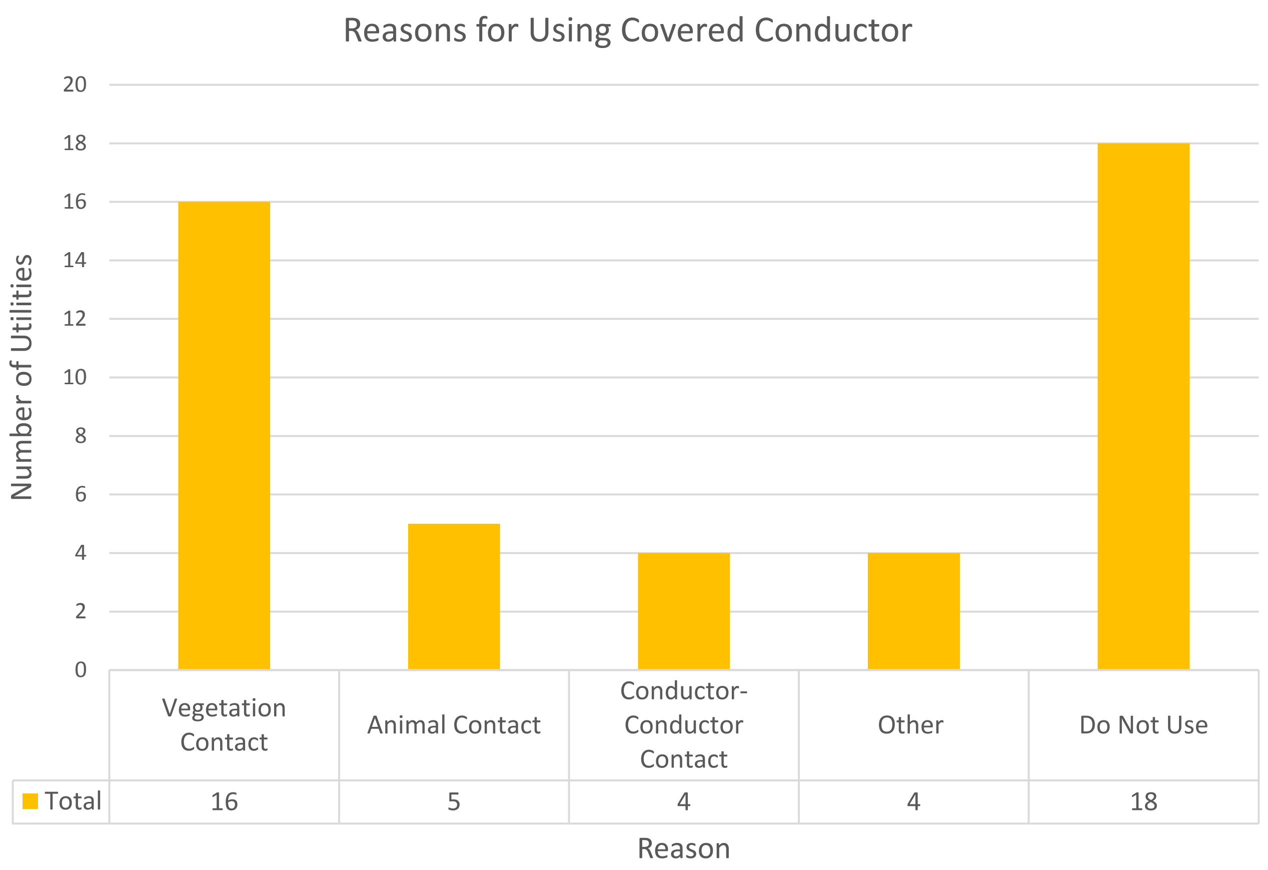
- Do you install covered conductor (Tree wire) for your primary (4 kV or higher) distribution lines?



- Do you install covered conductor (tree wire) for your branch line primary distribution wire? (fused, radial, two phases or less)



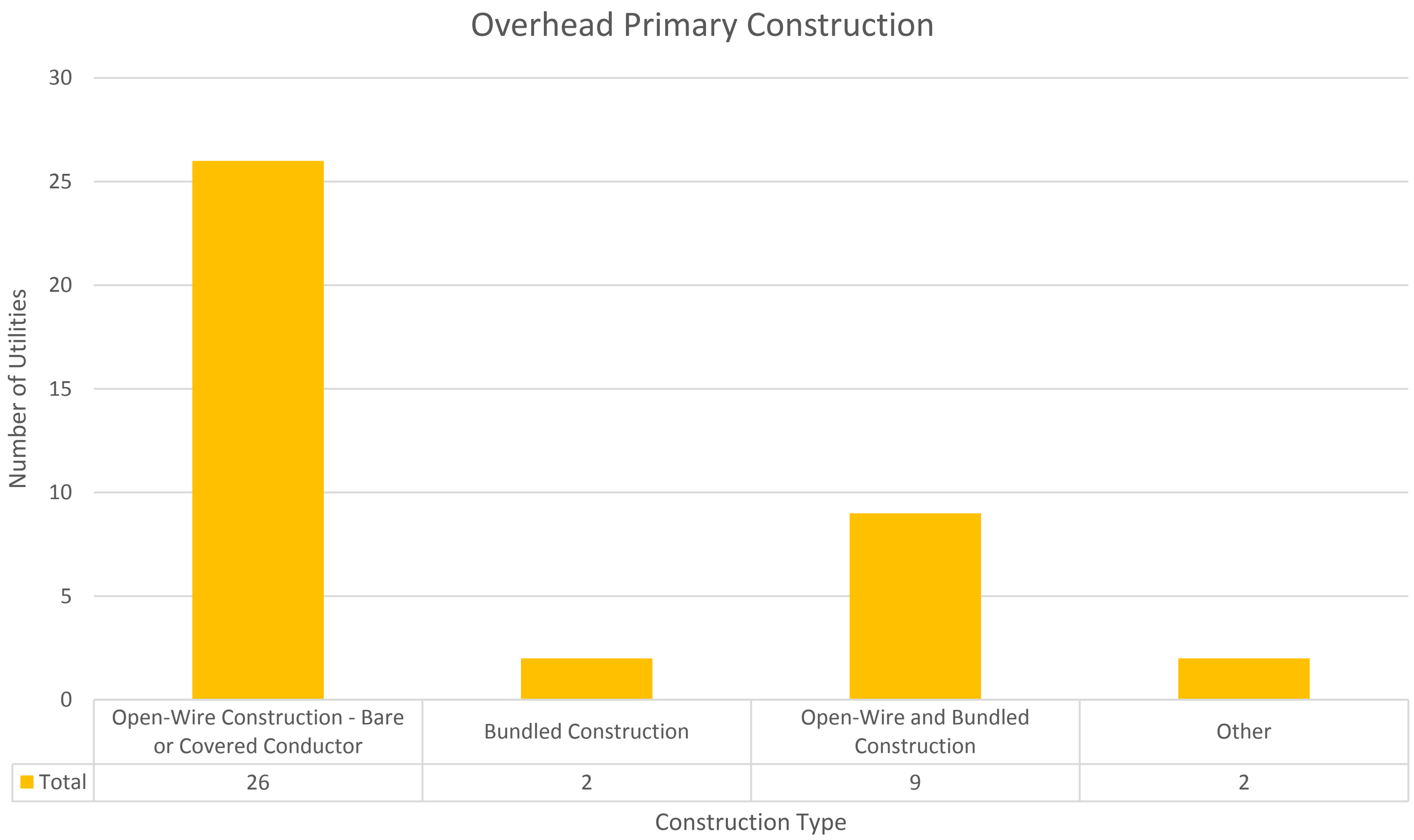
Reasons for Using Covered Conductor



Other

- Clearance and space management
- Higher density of circuit routing on a single pole

Types of Overhead Primary Construction Used



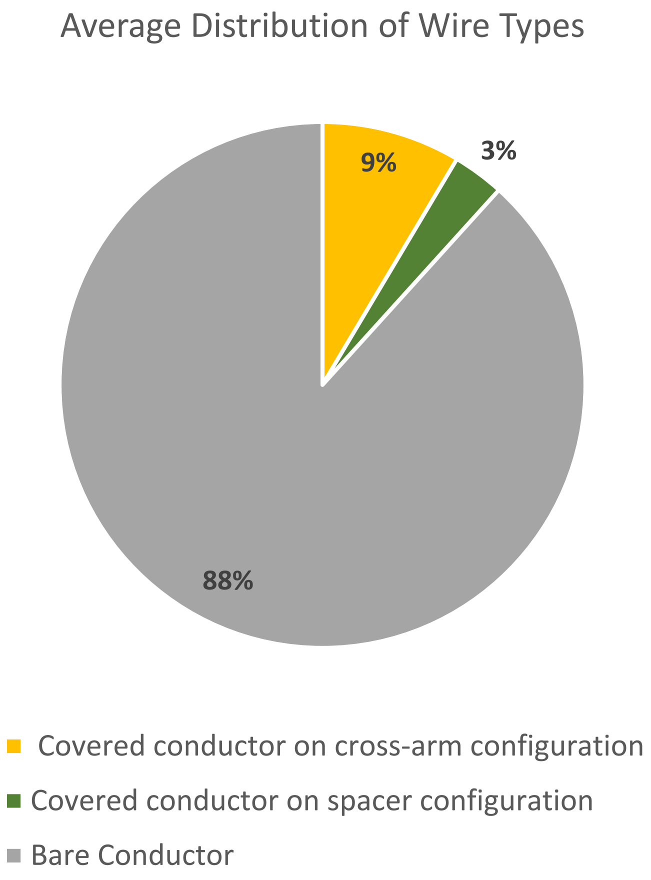
	Open-Wire Construction - Bare or Covered Conductor	Bundled Construction	Open-Wire and Bundled Construction	Other
Total	26	2	9	2

- Other
  - Armless Construction
- Open-wire can mean vertical or horizontal construction

Construction Criteria

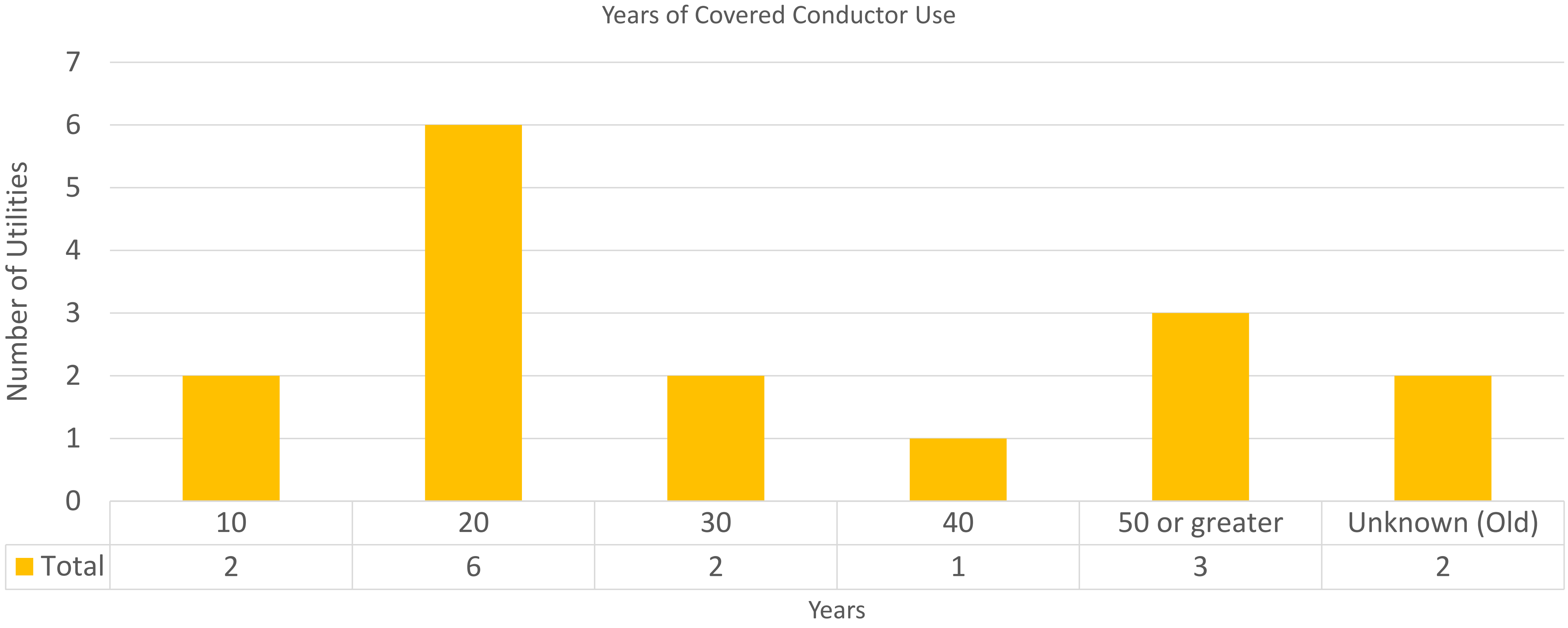
- Utilities typically use bundled construction in limited scenarios, which can include the following:
  - Use in areas in lieu of underground due to difficult trenching conditions
  - Express or dedicated feeders with limited or no taps
  - Limited right of way space
  - Heavily treed areas with tight clearances
  - Multiple circuits on a single pole
  - Storm hardening

Distribution of Various Wire Types



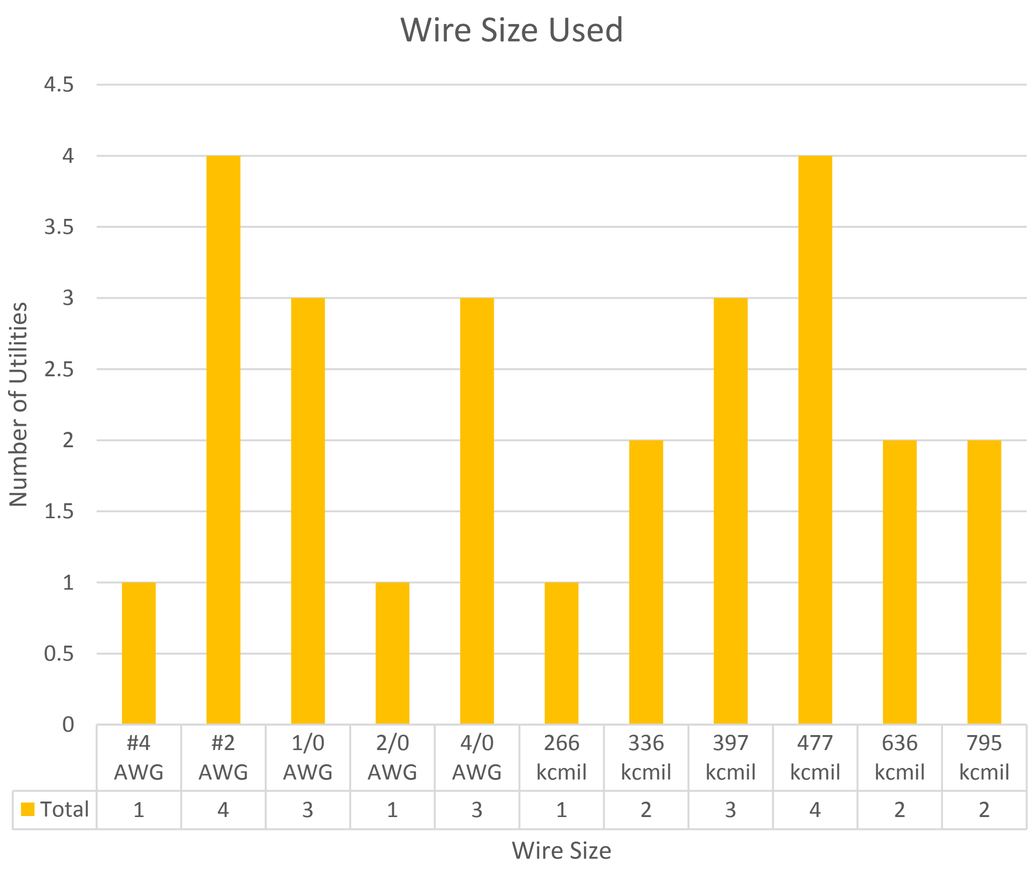
- On average, a utility's distribution system is made up of
  - 88% Bare Wire
  - 9% Covered Conductor on cross-arm configuration
  - 3% Covered Conductor on spacer configuration

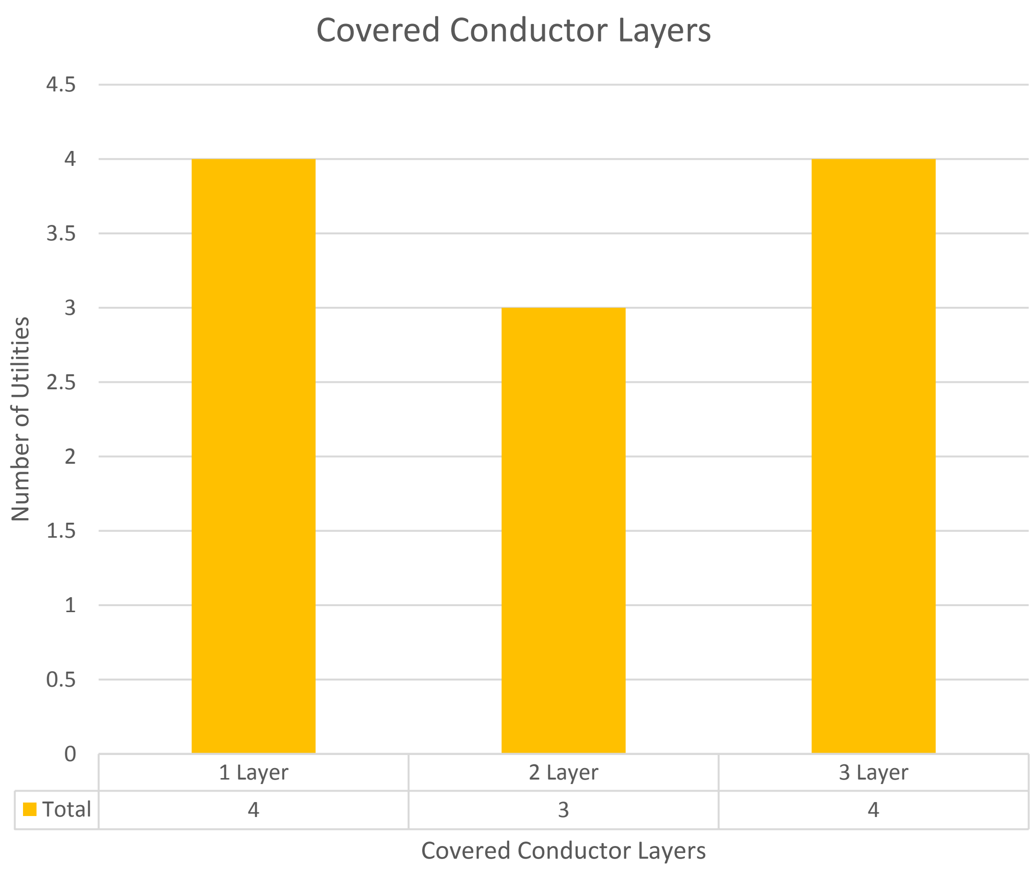
Years of Covered Conductor Use



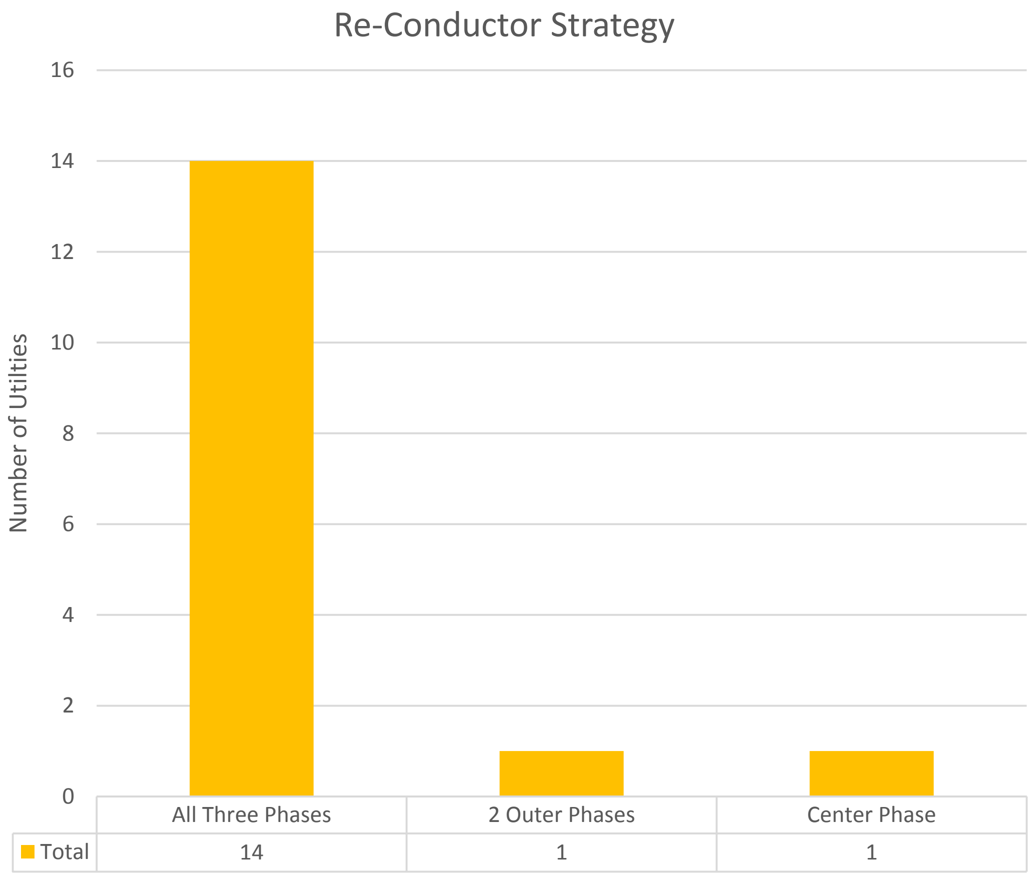
	10	20	30	40	50 or greater	Unknown (Old)
Total	2	6	2	1	3	2

Covered Conductor Wire Sizes and Layers



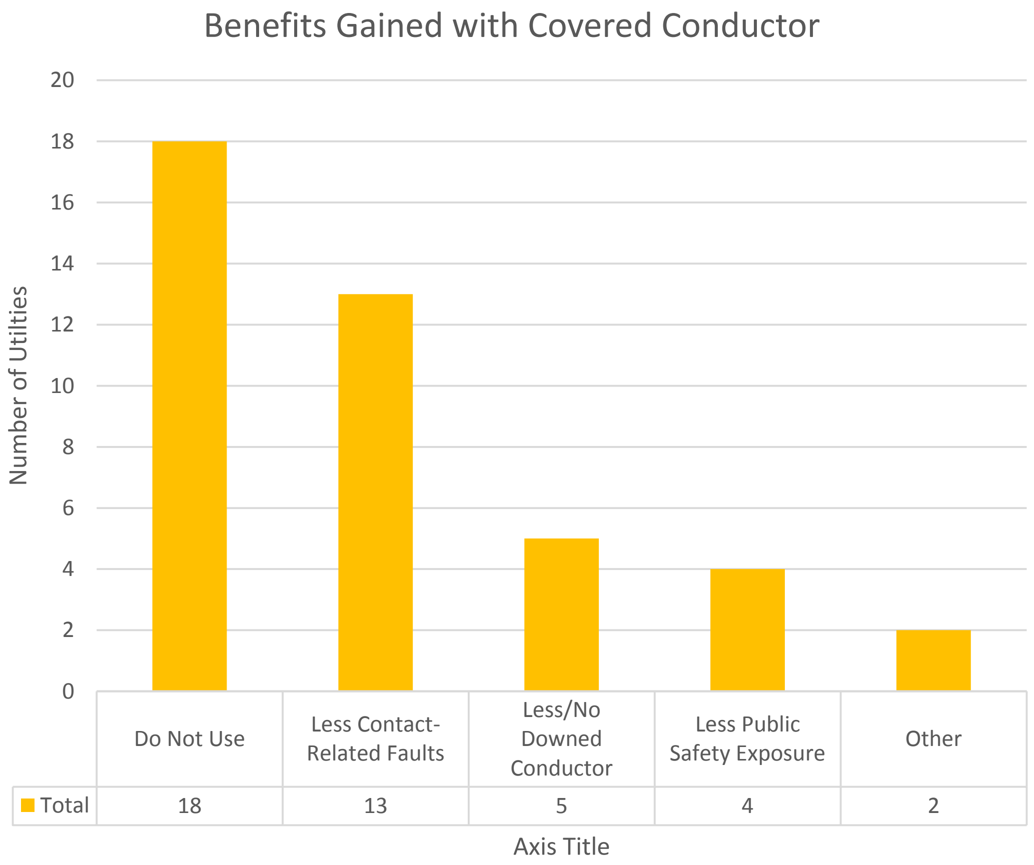


Re-conductoring Main Line



- All utilities indicated that they re-conductor all three phases when moving from bare wire to covered conductor
- One utility indicated that a standard does not exist and therefore performs all three options when re-conductoring to covered conductor:
    - All Three Phases
    - Two Outer Phases Only
    - Center Phase Only

Benefits Gained with Covered Conductor



- Other:
  - Utilities that answered “Other” indicated covered conductor caused more problems such as more downed conductor however, this experience is based on historical covered conductor systems (from 20 years ago or more).

4. Incorporating Lessons Learned

Known Challenges

The following challenges associated with covered conductor have been identified via research and benchmarking:

1. Aeolian Vibration
2. Abrasion
3. Electrical Withstand
4. Lightning Protection
5. Corrosion
6. Tracking
7. Burn Down
8. Wire Down Detection
9. Radio Frequency

Incorporating Lessons Learned

1. **Aeolian Vibration Limits**
   - Sag and Tensions for the covered conductor will take into account the terrain. There will be two separate tables for light and heavy loading. The loading limits account for wind and ice.
2. **Abrasion**
   - SCE's Covered Conductor design uses a Crosslinked High Density Polyethylene layer to help resist abrasion. Additionally, covered conductor must be handled with care in order to prevent damage to the covering.
3. **Electrical Withstand**
   - SCE uses a triple sheathed covered conductor design, which has been found to be the best choice for long term electrical withstand for trees and with adjacent phases. BIL of SCE's CC is 200 kV.
4. **Lightning Protection**
   - Surge arresters will be installed at all overhead equipment locations and at UG Dips.

Incorporating Lessons Learned

5. **Corrosion**
   - SCE will be using copper covered conductors in coastal applications.
6. **Tracking**
   - SCE's covered conductor design will include a track resistant XLPE outer layer. Additionally, SCE will mitigate tracking by using polymeric insulators, using crimped connectors, and using a low carbon content sheath.
7. **Burn Down of CC**
   - SCE will incorporate the following to prevent burn downs.
     - Suitable lightning protection (installation of surge arresters)
     - Reducing electrical stresses and carbon content on sheath material (polymeric insulator, low carbon XLPE, etc.)
     - Correct installation and tensioning (Sag and Tension will take into account terrain such as wind loading and ice)
     - Tree Trimming (SCE will maintain tree trimming requirements)
8. **Detection of Downed CC**
   - SCE will use SEF method of protection for covered conductors, which is the same protection scheme for bare wire.
9. **Radio Frequency Concerns**
   - SCE will use low carbon black content sheaths and polymeric insulators to significantly reduced tracking, thus reducing RF problem in coastal area.

Chapter IV
Covered Conductor Construction

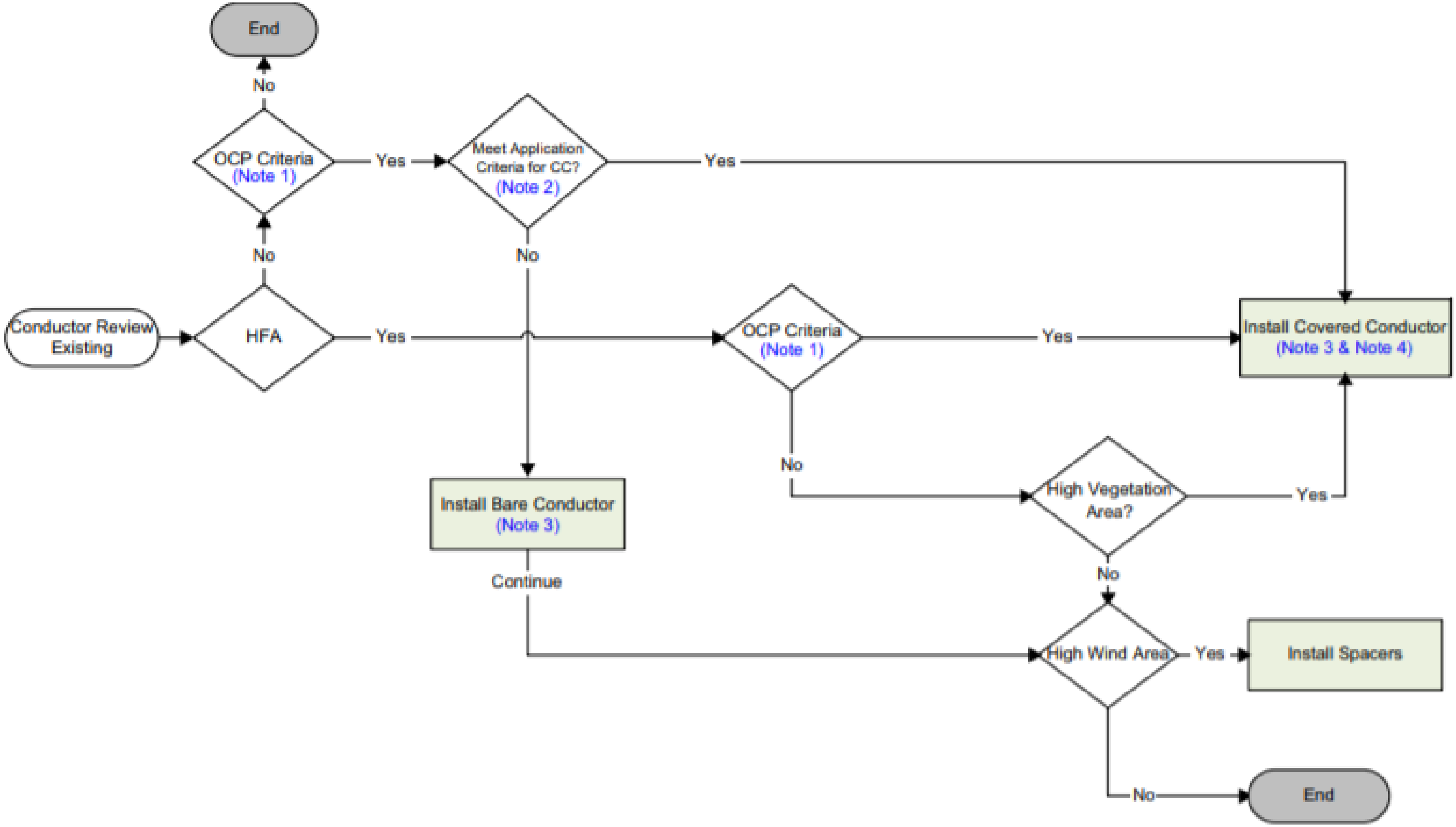
1. Covered Conductor Installation Guideline

This section discusses the covered conductor installation criteria

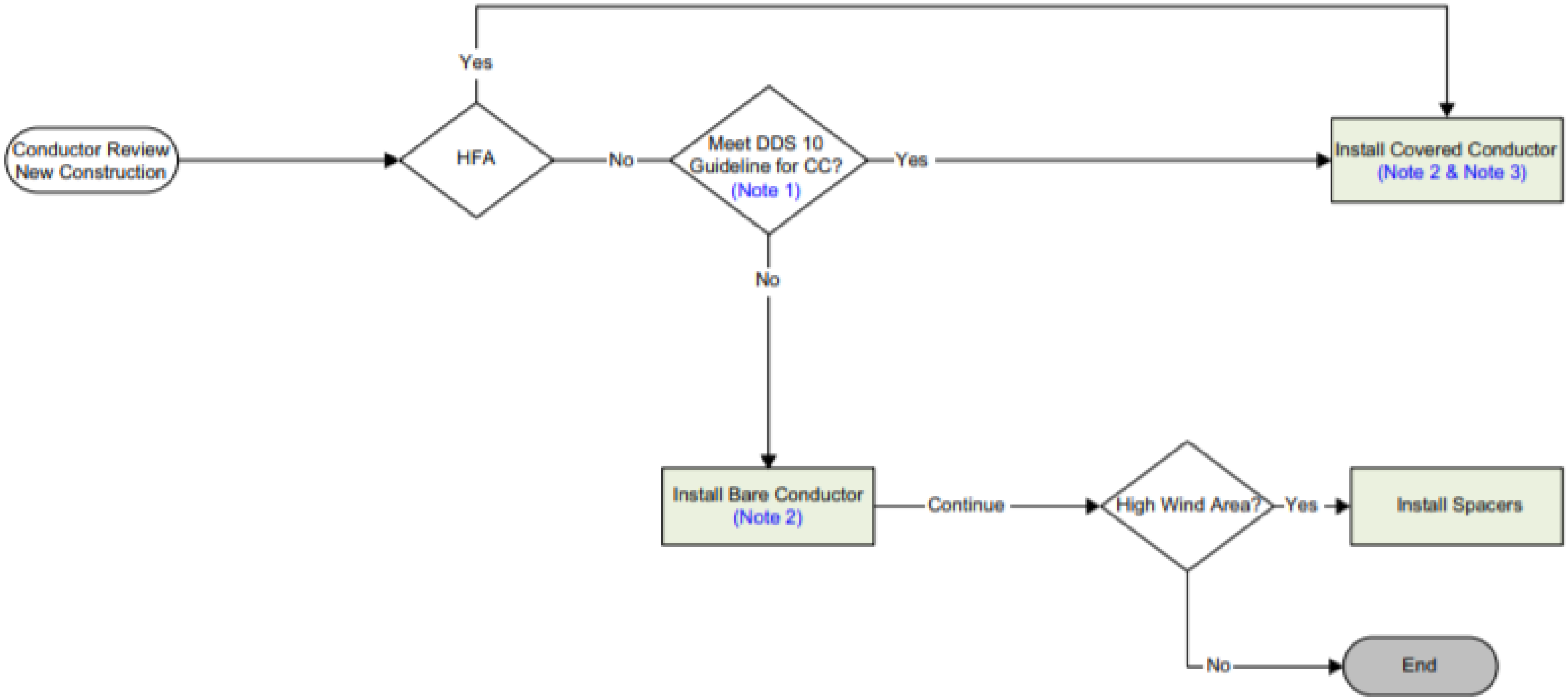
Covered Conductor Usage Criteria

1. System Operating Bulletin 322 Areas (HFRA)
2. Heavy vegetation with potential tree and palm frond contact
3. Known metallic balloon contact causing circuit outages
4. Any area with outages due to known intermittent contact
5. Coastal areas within one mile of the ocean
6. Reduced Tension Unguyed Spans
7. Any specific area that experiences accelerated corrosion

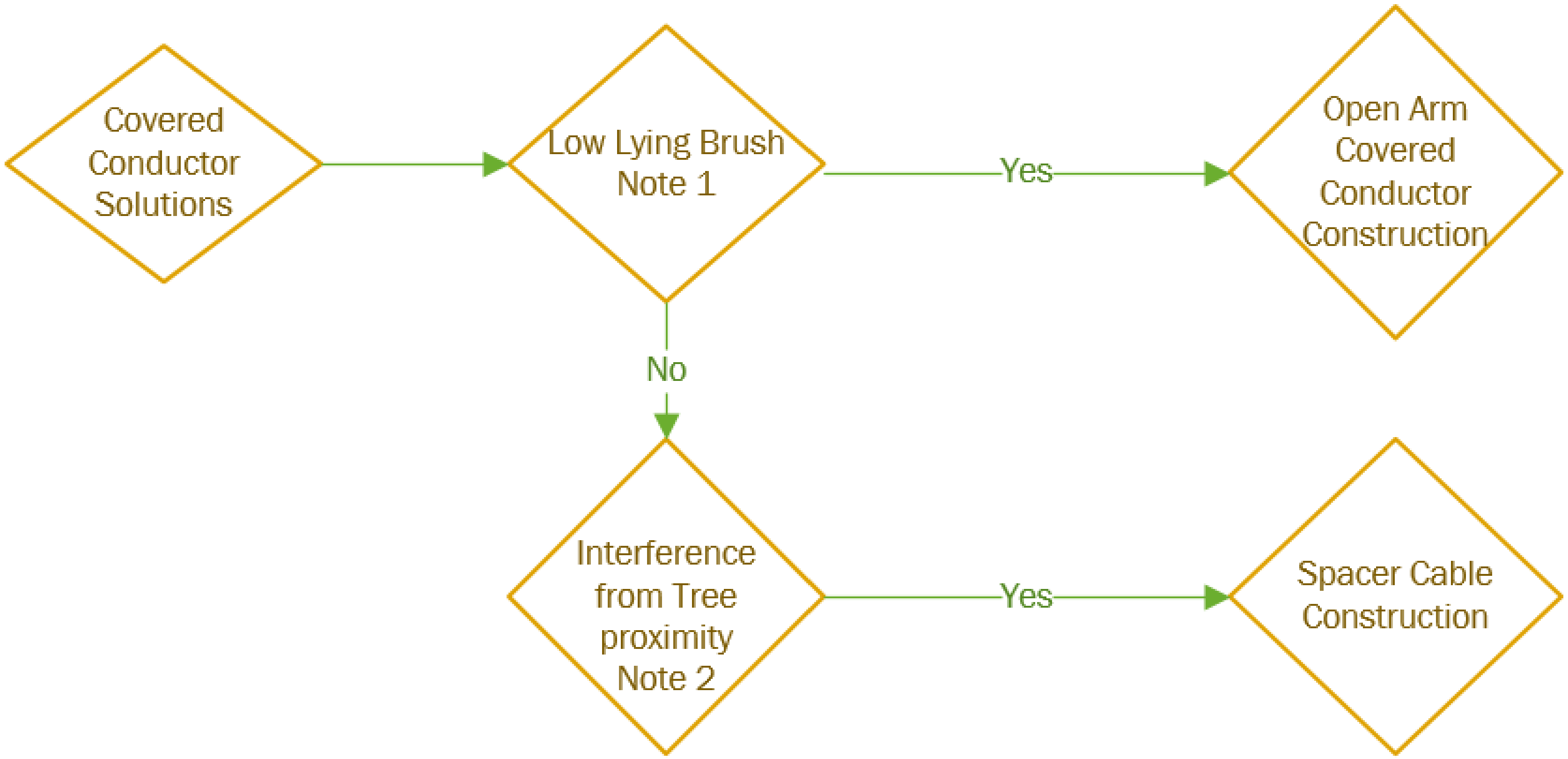
Installation Guideline– Reconductor/ Rebuild Existing Construction



Installation Guideline – New Construction



Covered Conductor Construction



- The geography of SCE's service area means less need for Spacer Cable construction in High Fire Risk Areas

Note1: Vegetation that has low potential to interfere with conductors, i.e. chaparral, brush below poles.
Note 2: Potential for intermittent tree line contact from branches or tree trunks. Vegetation management still required.

2. Covered Conductor on Three Phases and Neutral

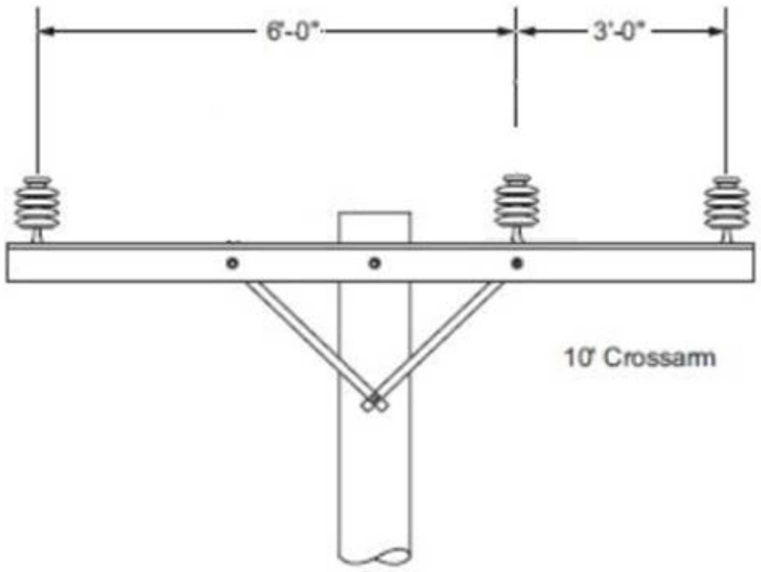
This section discusses the key factors considered to select covering all phases in SCE Standards

SCE Standards: Covered Conductor on Three Phases and Neutral

- Covered conductor will be used on all three phases in three-wire overhead system (mostly mainline)
- Covered conductor will be used on all two phases in overhead branch lines
- Covered conductor will be used on the neutral wire in four-wire overhead system (20% of SCE system has a neutral wire)

Analysis Factors

- Phase Spacing is key for the covered conductor
- This analysis will assume a three phase system. Refer to the figure below for phase spacing distances on a composite crossarm.



Evaluation of 1 Phase Covered

- In this configuration, it is assumed that only Phase B will be covered. Phase A and C will be bare wire.
- Analysis of effectiveness for mitigating phase to ground contact
  - This configuration will not be effective in preventing phase to ground contact. Phase A or Phase C will be susceptible to incidental contact with trees, therefore not eliminating the risk of a phase to ground fault.
- Analysis of effectiveness for mitigating phase to phase contact
  - This configuration will not be effective for phase to phase contact. There is 9 inches between the bare Phase A and Phase C. A foreign object or wildlife that is long enough could cause phase to phase contact. Palm fronds can be up to 13 feet long and California Condors have wingspans that are up to 10 ft long, which is enough to cause a phase to phase fault.
- Analysis of fire mitigation effectiveness
  - Covered conductor is considered effective for fire mitigation due to its ability to prevent incidental contact. However, its ability to prevent incidental contact will be compromised if the only one phase is covered.
  - Additionally, downed conductor is still possible due to mechanical failures or other equipment failure. The probability of a bare wire igniting a fire is higher than if it was covered.

2 Phase Covered

- In this configuration, it is assumed that Phase A and Phase C will be covered. Phase B will be bare wire.
- Analysis of effectiveness for mitigating phase to ground contact
  - This configuration will not be effective in preventing phase to ground contact. While the probability of a phase to ground contact is lower because Phase A and Phase C will be covered, Phase B will still be susceptible to incidental contact with trees, which will lead to a phase to ground fault.
  - Additionally, some equipment, such as transformers may be within 6 feet from the phases. Phase to ground faults may be possible due to incidental contact between the equipment and the center phase.
- Analysis of effectiveness for mitigating phase to phase contact
  - Because Phase A and Phase C are covered, the probability of phase to phase contact is reduced.
  - Internal SCE studies have shown that current through an object, such as a tree limb, connecting two phases of covered conductor is about 0.2 mA. This value doubles to 0.4 mA if the object is connecting a bare wire and covered conductor.
  - Insulation degradation on the covered conductor will happen at a faster rate, leading to failure happening at a faster rate.
- Analysis of fire mitigation effectiveness
  - The fire mitigation effectiveness is still less than if the system was fully covered. Phase to ground incidental contact is still possible even with two phases covered, leading to arcing that could cause ignition.
  - Furthermore, downed conductor is still possible due to mechanical failure or other equipment failure. The probability of a bare wire igniting a fire is higher than if it was covered.

Evaluation of 3 Phases Covered

- In this configuration, it is assumed that Phase A, Phase B, and Phase C will be covered.
- Analysis of effectiveness for mitigating phase to ground contact
  - Because the system is fully covered, there is a very low probability of incidental contact causing phase to ground faults.
- Analysis of effectiveness for mitigating phase to phase contact
  - Because the system is fully covered, there is a very low likelihood of incidental contact causing phase to phase faults.
- Analysis of fire mitigation effectiveness
  - Covered conductor is considered effective for fire mitigation due to its ability to prevent incidental contact. By fully covering all three phases, the possibility of faults due to incidental contact is greatly reduced.
  - If a downed wire scenario were to happen, covered conductors are less likely to cause a spark that bare wire. Therefore, the chance of ignition has been greatly reduced.

Neutral Covered

- In this configuration, it is assumed that Phase A, Phase B, Phase C and the Neutral will be covered.
- Analysis of effectiveness for mitigating phase to neutral contact
  - Because the system is fully covered, there is a very minute likelihood of incidental contact causing phase to phase faults.
- Analysis of fire mitigation effectiveness
  - In a downed wire scenario, a covered neutral will be less likely to cause a spark than a bare neutral.
  - Chance of ignition is reduced

Other Factors to consider

- Sagging
  - Covered conductor and bare wire are sagged at different tensions
  - If covered conductors were to be sagged like bare wire, it may cause vibration problems
  - Covered conductors have more sag than bare
  - Mixing bare and covered conductor in one crossarm will cause uneven sags
  - Uneven sags may increase the risk of conductor slapping, leading to an increased chance of insulation degradation, arcing, and ignition.
- Benchmark
  - Other utilities use a 3 phase covered system

Conclusion

- Partially covering the system (1 phase covered, 2 phase covered, bare neutral) will dilute the effectiveness of covered conductor.
- Using covered conductor for all three phases and the neutral promotes SCE's grid resiliency and the elimination of an ignition source.

3. SCE Covered Conductor Open Cross-arm Construction

This section illustrates how Covered Conductor and Wildlife Covers being used in SCE Standards to achieve maximum protection from incidental contacts

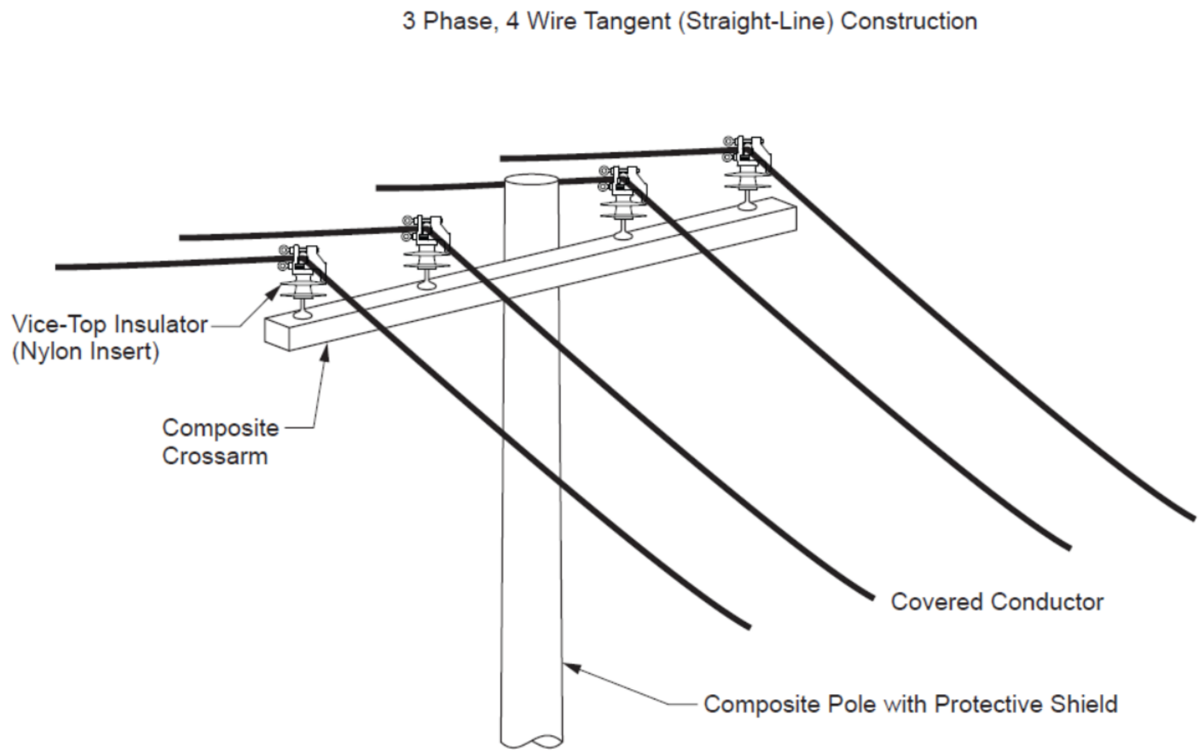
SCE Construction Diagrams

- SCE’s covered conductor systems will be all covered
- This includes wildlife covers on dead-ends, terminations, and equipment bushings, jumper wires
- Also illustrated are other Wildfire resilient equipment/hardware, such as composite pole, composite cross-arm, polymer insulator for covered conductor
- These illustrations depict the four common pole configurations:
  - Tangent pole: means covered conductor pass thru insulators
  - Dead-end pole: covered conductor will stripped off to connect to dead-end insulator
  - Transformer pole: stripping cover required for connecting to transformer (or equipment)
  - Riser pole: stripping cover required to connecting to underground cable

Tangent 4 Wire Construction and Splicing

Tangent pole does not need other covering hardware

- **Tangent Construction**
- All Wires, including Neutral will be covered
- Use Polymer Insulator
  - Using material with different dielectric properties will cause a voltage gradient and induce voltage stress, causing the insulation to degrade over time



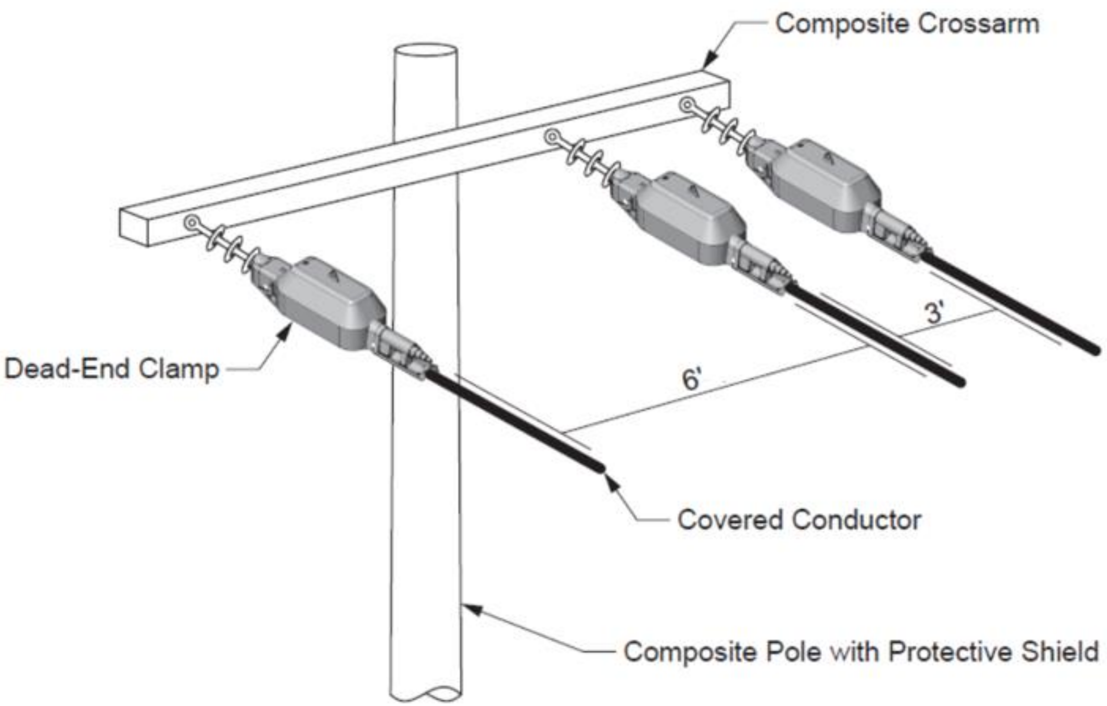
Same concept for three-wire and two-wire constructions

Three-wire Dead-end Construction

Introduce new standards for dead-end cover, composite pole and cross-arm

- Covered Conductors need to be stripped at the dead-end
- Use Dead-end Covers to protect exposed areas

Single Dead-End (3 Phase, 3 Wire) Construction

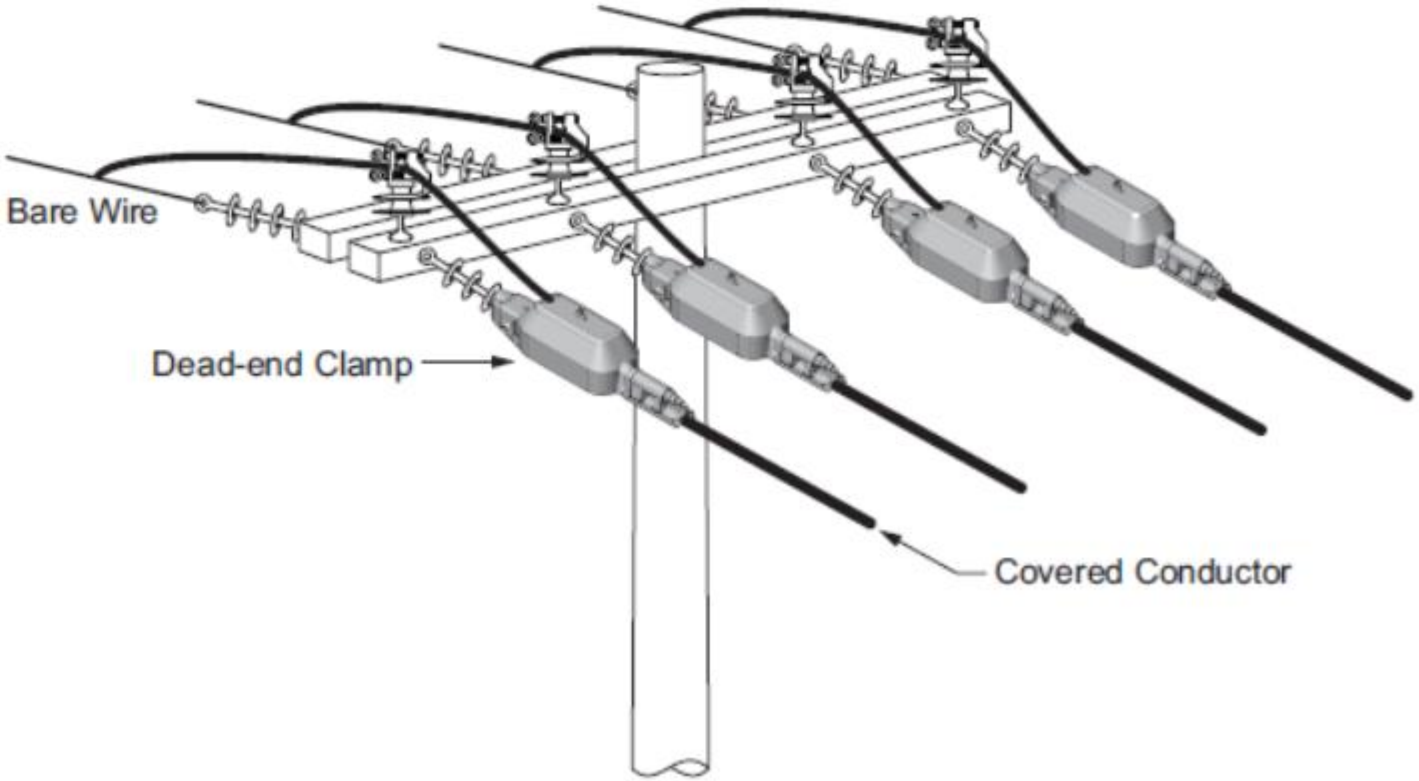


Same concept for four-wire and two-wire constructions

Bare Wire to Covered Conductor Transition

- Use dead-end pole when transitioning from bare wire to covered conductor
- Splices are not allowed when transitioning from bare to covered

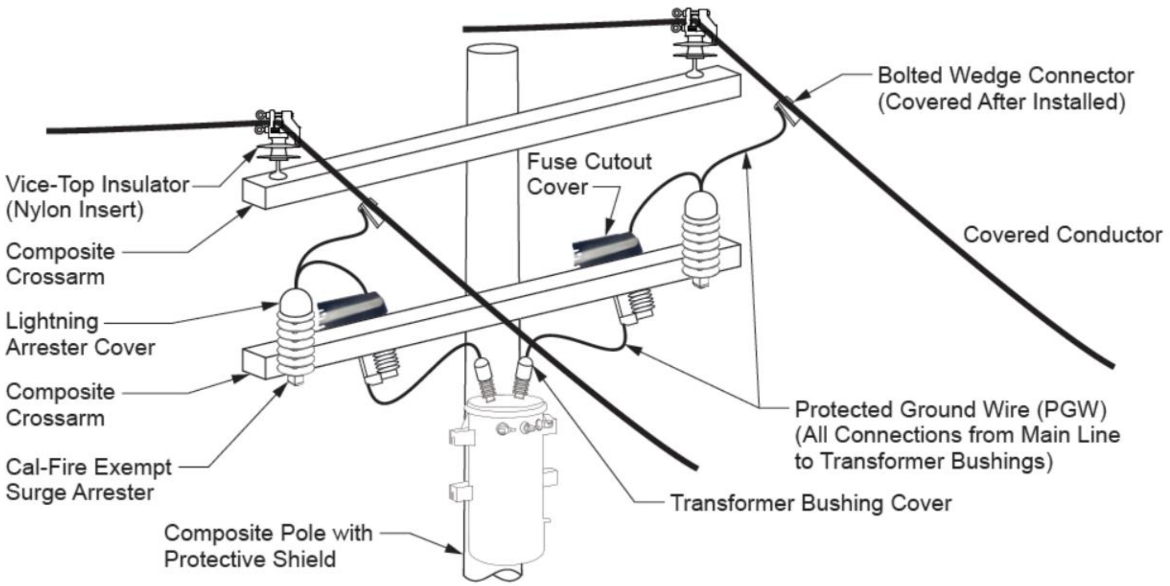
Figure CC 180–1: Covered Conductor to Bare Wire Transition



Tangent 2 Wire with Transformer Construction

- **Use Surge Arresters at all Overhead Equipment**
  - Treat Covered Conductor systems like high lightning area
  - Covering prevents the arc from moving
- **Use Bolted Wedge Connector**
  - Cover after installation
- **Use Protected Ground Wire**
  - Connections to equipment will be covered
- **Wildlife protection on equipment**
  - Cover Lightning Arrester, Transformer Bushing, and Fuse

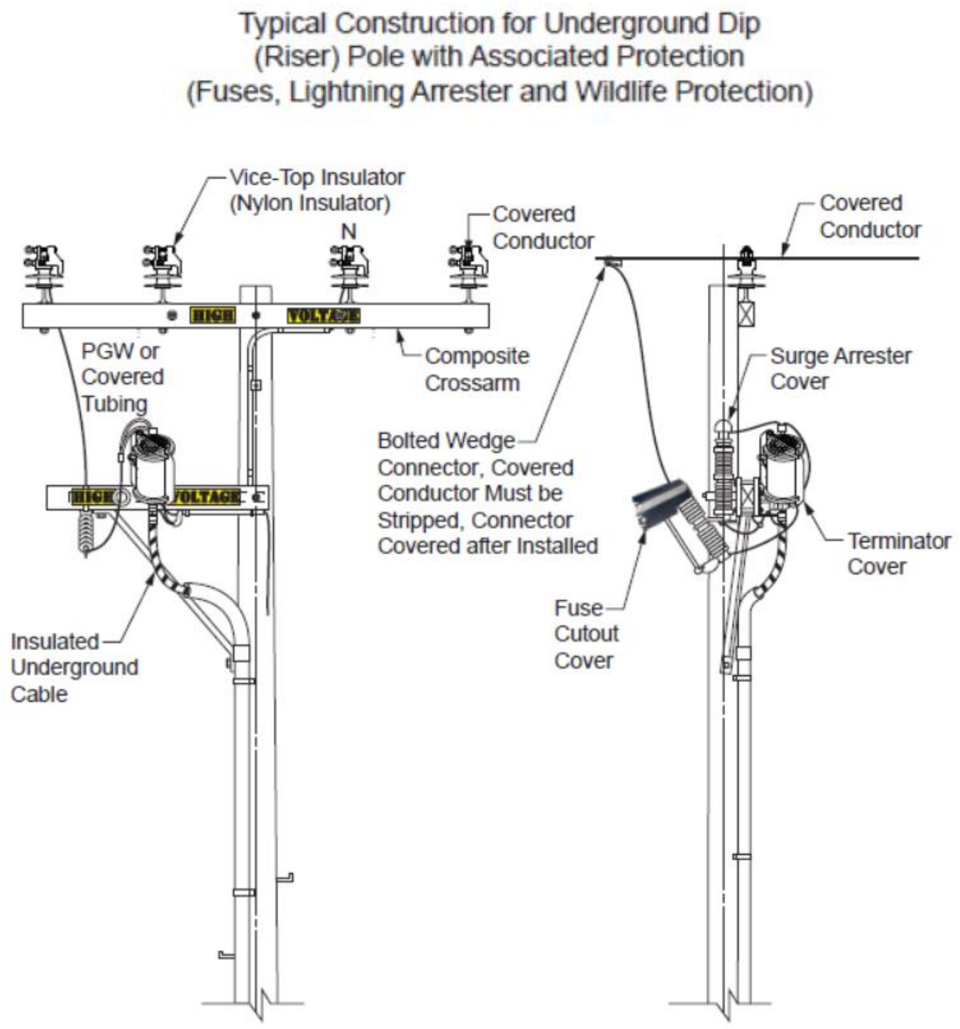
Overhead Transformer with 2 Phase, 2 Wire Tangent (Straight Line) Construction and Associated Protection (Fuses, Lighting Arresters, Wildlife Guards)



Same concept for connecting to other equipment: capacitor, switch, remote automatic recloser, etc.

Riser Pole Construction

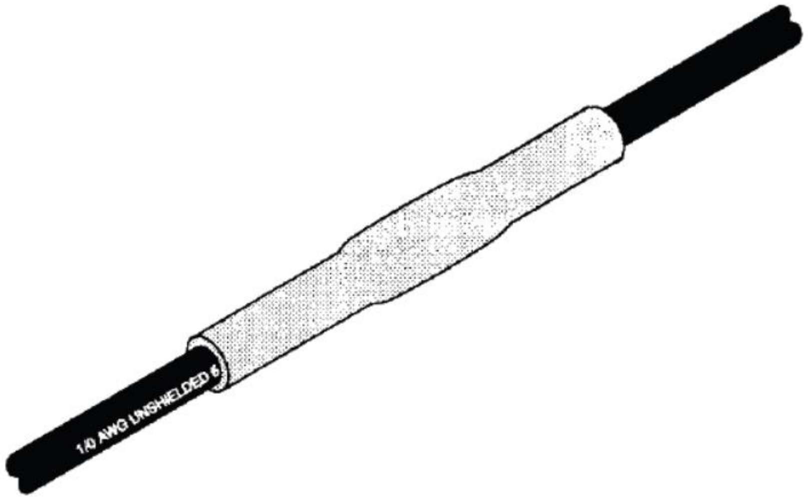
- **Use Surge Arresters at all UG Dips**
  - Treat Covered Conductor systems like high lightning area
- **Cover Terminations**

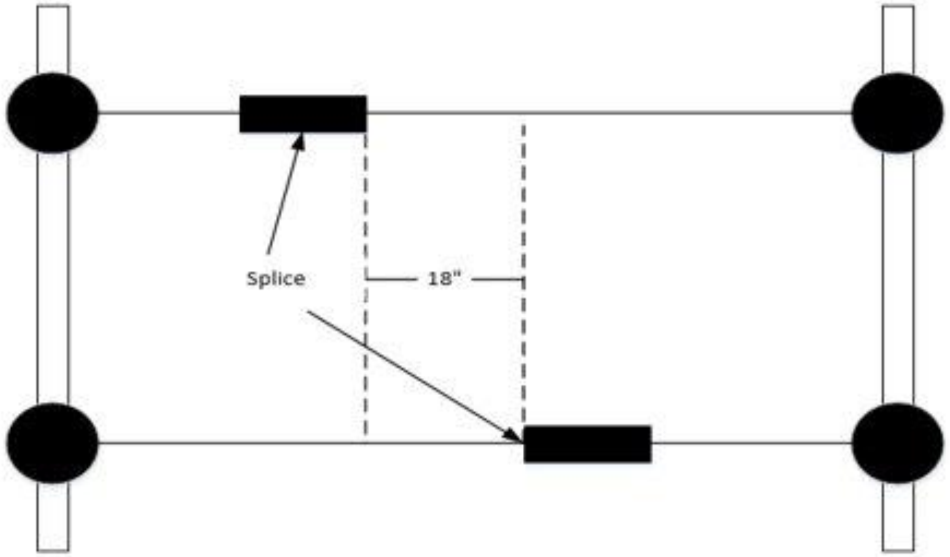


Same concept for three-wire and two-wire constructions

Splices

- Splices will be covered
- Splices for adjacent conductors shall not be installed next to each other and should be staggered 18 inches end to end.

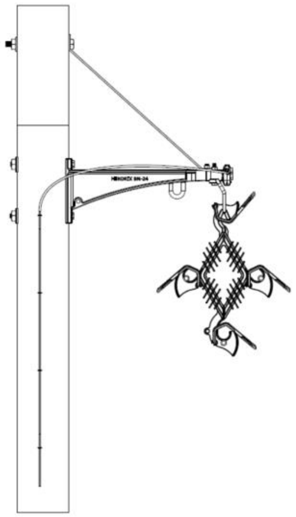


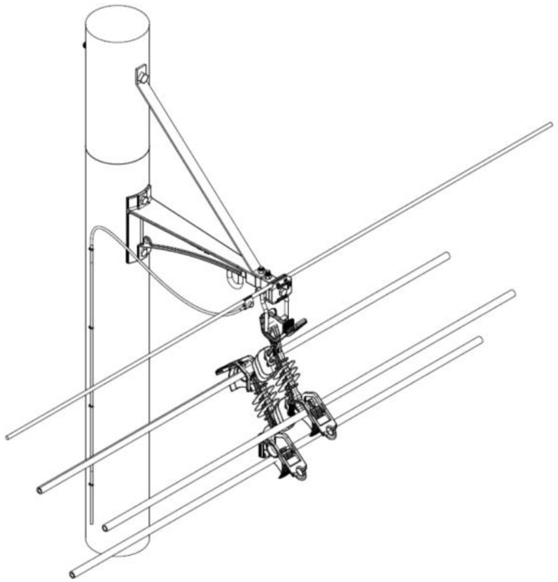


4. SCE Spacer Cable Construction

Spacer Cable – Technical Specifications

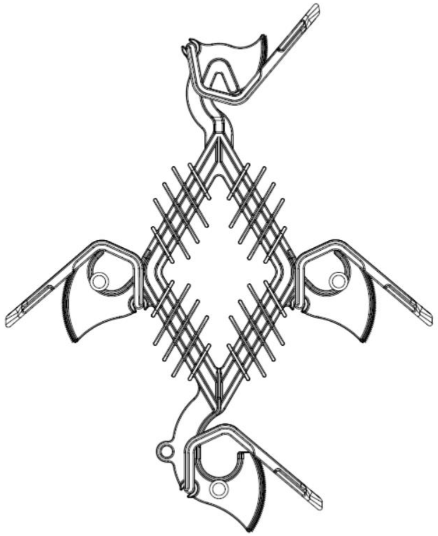
- Spacer Cable system:
  - A high-strength (alumoweld) messenger suspends the weight of the covered conductors through a diamond shaped spacer bracket.
  - Insulated spacers installed at a 30-foot interval with a spacing of 12 to 18 inches (spacer bracket dependent) between conductors.
  - Covered Conductors are the same SCE specification in both open cross arm as well as spacer cable.





Spacer Choice

- Southern California Edison will use a 12 and 18 inch spacer bracket.
  - In areas where contamination is deemed to be moderate to low the 12" bracket will be utilized.
  - In areas where heavy contamination is elevated an 18" bracket shall be used.



Spacer Cable – Areas of Install

- Areas of Installation
  - High Vegetation areas.
  - Areas with tree and branch overgrowth.
  - Areas where intermittent contact with vegetation is possible.
  - Conductor Spans of Great Length.

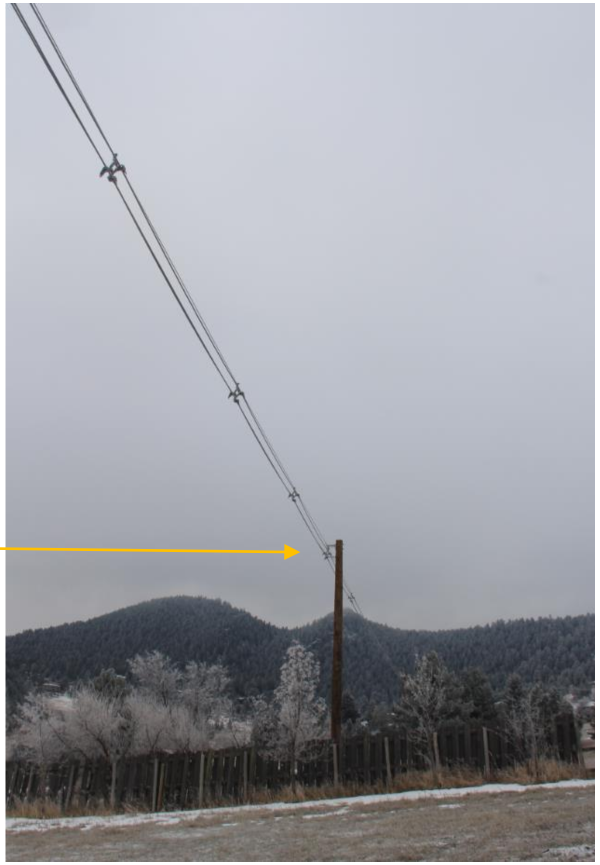
In all areas of installation vegetation management is still a requirement.

Clearance is acceptable but overgrowth can be effected in storm conditions.

Construction of Spacer

Tangent Poles:

- 24” Tangent Bracket
- 12” Bracket (Dependent of Contamination)
- Messenger is sized per span length and conductor size.
- Messenger to be grounded at approximately 600 foot intervals or less.



Chapter V
SCE Covered Conductor Installations

Energy for What's Ahead[SM]

SOUTHERN CALIFORNIA EDISON®

1. Chawa Covered Conductor Installation

Site

Site on March 7, 2019

Site During Dry Seasons

Covered Conductor on Tangent Pole

Covered Conductor with Pole Switch

Covered Conductor with Transformer

2. Davenport Covered Conductor Installation

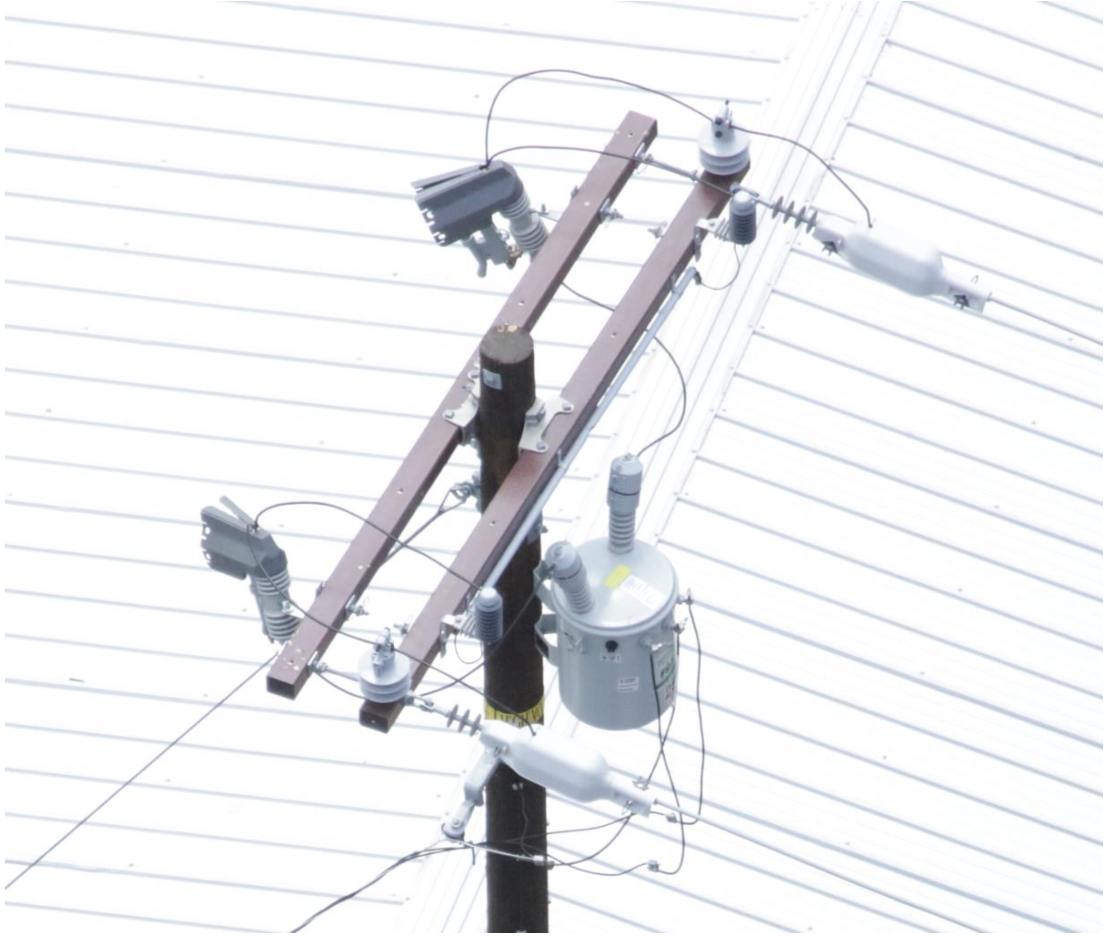
Covered Conductor on Tangent Pole

Horizontal Construction

Ridgepin Construction

Covered Conductor Double Dead-end

Covered Conductor Dead-end with Transformer



Covered Conductor Corner Pole

Covered Conductor and Underground Dip

Tangent

Dead-end

Covered Conductor Real-World Success at SCE

Tree Fall on Covered Conductor

- Event
  - Eucalyptus tree fell on energized covered conductor in Malibu on January 16, 2019.
    - Tree laying across all 3 phases for two hours with no circuit interruption
- Outcome
  - No Fault
    - Covered Conductor covering prevented a phase-to-phase and phase-to-ground fault
  - No Wire Down
    - Covered conductor and composite crossarm did not break under the weight of the tree
  - No Ignition
    - Covered Conductor prevented a fault that could lead to possible ignition
    - Ignition due to wire down was prevented due to covered conductor not severing upon the weight of the tree