INTRODUCTION

This document applies to inspection and maintenance of all overhead National Grid US Transmission and Sub-Transmission assets as defined by NG EOP T007.00. This procedure shall be executed by Qualified Personnel as determined by training specific to the task.

PURPOSE

This procedure defines the requirements for electrical connector inspection and maintenance of Transmission and Sub-Transmission assets.

ACCOUNTABILITY

Specific planned inspections performed under this procedure will be coordinated by the following work groups via a Work Plan document to be released prior to the start of each fiscal year.

1. T&D Work Methods
   A. Update procedure as necessary
2. Project Management & Complex Construction / Electric Operations
   A. Ensure that this procedure is understood and implemented
   B. Ensure that all personnel are trained in this procedure
   C. Repair problems found during inspections according to follow-up prioritization criteria
3. T&D Maintenance / Electric Operations / Inspections
   A. Schedule and coordinate inspections for transmission and sub-transmission assets
   B. Ensure inspections as outlined in the fiscal year work plan are safely executed according to the stated procedures and performed in a timely manner.
   C. Ensure worker understanding and comprehension of the requirements of this EOP.
4. Employee
   A. Demonstrate the understanding of this procedure
   B. Comply with the requirements of this procedure

COORDINATION

National Grid Project Management & Complex Construction
T&D Maintenance
Electric Operations
Inspections

REFERENCES

National Grid Employee Safety Handbook
NG-EOP T007.00 Line Inspection and Maintenance Activities
NG-EOP T007.01 Ground Level Visual Inspection
NG-EOP T007.02 Aerial Visual Inspection

DEFINITIONS

Baseline Temperature: The reference temperature at which transmission assets should be normally operating

Conductor: A current carrying wire

Delta Temperature (Delta-T): The difference between an objects temperature and the baseline temperature

Down Grounds: A non-current carrying wire used to ground transmission lines often attached vertically to a transmission structure and connected to ground

Electrical Connector: Any current carrying component connected to a conductor such as a splice or terminal connector

Emissivity: A property of a material that describes the efficiency with which radiates energy by comparing it to a blackbody (a perfect radiator) at the same temperature. Emissivity values range from zero (lower efficiency) to one (higher efficiency)

Hardware: Supporting mechanical component such as clamps, clevis type connectors, bolts

Insulator: Any dielectric component used to electrically isolate conductors from ground such as porcelain, polymer or toughened glass

Line Assets: Overhead equipment such as conductors, electrical connectors, shield wires, structure down grounds, hardware, switches, wave traps, in-line cutouts

Qualified Personnel: Personnel trained to safely perform a specific inspection

PM&CC: Project Management & Complex Construction

Riser Structure: A structure that supports the transition of an underground electric cable to an overhead transmission line

Shield Wire: A non-current carrying wire used to protect a transmission line from lightning strikes.

Thermographer: A person who is qualified to use thermographic imaging equipment.

Work Plan: A document published each fiscal listing all planned inspection and maintenance scheduled for the year

TRAINING

Provided by L&D upon request by user department

DOCUMENT CONTENTS

Table of Contents

1.0 BACKGROUND

1.1 Electrical connectors degrade due to:

- 1.1.1 Normal wear
- 1.1.2 Contamination
- 1.1.3 Corrosion
- 1.1.4 Fatigue
- 1.1.5 Faulty assembly
- 1.1.6 Poor installation

1.2 Degradation frequently creates a rise in electrical resistance and temperature

- 1.2.1 Increased resistance occurs first
- 1.2.2 Temperature rise occurs later
- 1.2.3 Non-current carrying components can also display rises in temperature
  - a. Shield wires
  - b. Down grounds
  - c. Hardware

1.3 Infrared thermography identifies components which have a temperature rise vs. the surroundings

1.3.1 Temperature rise is the difference between the baseline temperature of a normally operating component and the temperature of a component that is heated

a. Called the delta-temperature (Delta-T)

b. Commonly referred to as a hot spot

1.3.2 Reliable detection and calculation of Delta-T can be hampered by:

a. Atmospheric conditions

1. Wind speed
2. Ambient air temperature
3. Solar heating
4. Precipitation

i. These factors may reduce Delta-T below the threshold of detection

b. Emissivity

1. Effects hot spot detection and Delta-T assessment
2. Generally between 0.1 and 0.3 for new components
3. Approaches 0.9 for aged components
4. Can be difficult to assess

i. In flight

ii. From a distance

5. Of adjacent components can also differ

i. Conductor and splices

ii. Complicates the assessment

6. Infrared camera emissivity settings must be properly adjusted

i. For best assessment of Delta-T

c. Line loading

1. Greatly influences Delta-T

i. Low line loadings = low Delta-T

ii. Difficult to detect a degraded connector

2. Connectors appearing to be Level 3 status

i. Under low to moderate line loadings

ii. Could be Level 1 or 2 as line loading increases

1.4 Resistance measurement is an extremely accurate method for assessing electrical components

1.4.1 Requires direct contact of a resistance meter to live electrical equipment

1.4.2 Significantly more costly and time consuming than infrared inspection

a. Use is limited

2.0 INSPECTION INTERVAL AND CONDITIONS

2.1 Infrared inspection intervals are specified in EOP T007.00

2.1.1 Some lines may be inspected twice per year upon request

2.2 The following guidelines shall be used to assign inspection techniques

2.2.1 Inspections shall occur during the summer peak load period

a. June, July or August

1. Aids in detection of Delta-T

2. Lines shall not be artificially loaded to induce peak load conditions

2.2.2 If a second inspection is requested it shall occur during the winter peak load period

a. December, January or February

2.2.3 Second inspection recommended for lines with

a. 5 failed connectors in 5 years

b. 5 degraded connectors in 1 year

2.3 Resistance measurement

2.3.1 Lines of poor reliability may be inspected by resistance measurement

a. As requested by T&D Maintenance or Electric Operations

b. Recommended on lines with more than

1. 5 failed connectors in 5 years

2. 5 degraded connectors in 1 year

3.0 THERMAL INSPECTION

3.1 Thermographer Qualifications

3.1.1 Inspections shall only be performed by a Level 1, 2 or 3 Thermographer

3.1.2 Certifications shall be submitted prior to an inspection cycle

3.2 Inspection Patrol

3.2.1 All overhead transmission and sub-transmission line assets shall be thermally inspected and included in the work plan.

3.2.2 The demarcation point between

a. Transmission line and a substation

1. Where the transmission line insulator string connects to the substation structure

b. Overhead and underground transmission

1. Cable termination connector

i. On a riser structure

3.2.3 Lines must be energized for infrared inspections to be valid

a. Verified as energized with transmission dispatch

3.2.4 Structure and substation coordinates shall be supplied by T&D Maintenance or Electric Operations upon request.

3.2.5 See Appendix A for typical asset types

3.3 Infrared Camera

3.3.1 Short wave or long wave allowed

a. For short wave camera

1. Thermographer must discern between solar reflection and hot spots

3.3.2 Calibration shall be per camera manufacturer's specifications

3.3.3 Shall be calibrated daily and adjusted as conditions require

a. Calibration documentation shall be submitted to T&D Maintenance or Electric Operations as appropriate

3.4 Camera Settings

3.4.1 Can greatly affect the ability to accurately calculate temperature rise and detect elevated temperatures

3.4.2 Shall be properly adjusted for the conditions

a. Emissivity

1. Thermographers shall estimate component emissivity to the best of their ability

i. Emissivity of conductors and connectors is 0.1 to 0.3

ii. Weathered or aged conductors and connectors can approach values of 0.9

iii. Asset age data can be provided by National Grid

b. Distance to target

c. Temperature reflected

d. Ambient temperature

e. Relative humidity

3.5 Baseline temperature

3.5.1 Required in order to calculate the temperature rise of a hot spot

3.5.2 Shall be taken from like devices

a. Adjacent dead end shoe

b. Nearby conductor for a hot splice

c. Etc.

3.6 Predicted Temperature Rise

3.6.1 Adjust the delta temperature from the survey

a. Becomes the predicted temperature rise

b. Provides better assessment of the risk of failure

c. Takes into account the line loading in MW

3.6.2 Calculation of predicted temperature rise is shown below

$$T_{pr} = \left(\frac{L_r}{L_a}\right)^2 \times \Delta T \times F_w$$

Where:

T_{pr} = Predicted temperature rise

L_r = Load rating of the circuit in amps

L_a = Actual load of the circuit at the time of measurement in amps

ΔT = Measured Delta T

F_w = Wind speed adjustment factor[1] per Table 1

Table 1

Wind Speed, mph	Wind speed adjustment factor, F_w
0 - 5	1

[1] These factors are an approximation which can apply to most cases. For a higher degree of accuracy, IEEE Standard 738-2006 may be used.

> 5 - 10	1.3
> 10 - 15	1.4
> 15	1.5

3.7 Temperature Guidelines

3.7.1 Tables 2 & 3 describe the course of action for certain ranges of temperature rises. These rises shall be reported to TLS

Table 2
Line Equipment Action

Predicted Temperature Rise (°C)	Action
1-10	Level 3
11 – 40	Level 2
41 and above	Level 1

Table 3
Device Equipment Action
(Including Switches and Riser Structures)

Delta-T (°C)	Action
1 - 20	Level 3
21 - 60	Level 2
61 and greater	Level 1

3.8 Reporting

3.8.1 Location of hot spots shall be reported to:

a. Inspections

b. T&D Maintenance

3.8.2 See Format in Appendix C

4.0 RESISTANCE MEASUREMENT

4.1 Qualifications

4.1.1 Resistance measurements shall be performed by PM&CC personnel

4.2 General

4.2.1 Resistance measurements shall be taken to verify

a. Hot spot locations

b. Successful repairs during live line hot spot repairs

1. Optionally - taken on all other hot spot repairs

c. At nearby fittings that did not show elevated temperatures

1. Adjacent dead-end clamps at a dead-end structure

2. Nearby splices in the same or adjacent phases of the same span

3. Etc.

4.2.2 Fittings typically show signs of increasing resistance before elevated temperatures are detected.

4.2.3 Resistance measurements may also be taken on lines of declining performance

a. Or as specified by

1. T&D Maintenance

2. Electric Operations

4.3 Equipment shall be

4.3.1 Sensor Link (“Ohmstik”)

4.3.2 Other devices approved by T&D Work Methods

4.3.3 Approved for use on voltages of 69kV to 345kV

4.4 Resistance measurements

4.4.1 Shall be taken on

a. The line conductor adjacent to a hot splice

1. Distance between probes slightly more than ½ connector length

b. The left side of the hot splice

1. From the center of the splice to the conductor just outside the splice

c. The right side of the hot splice

1. Same as b1 above

4.5 Calculate the resistance ratio

4.5.1 Divide the left side resistance by the line resistance

a. This is the ‘Left Side Ratio’

4.5.2 Divide the right side resistance by the line resistance

a. This is the ‘Right Side Ratio’

4.5.3 Compare each ratio to the values in Table 4

a. Determine the action required

b. Report the ratios to PM & CC

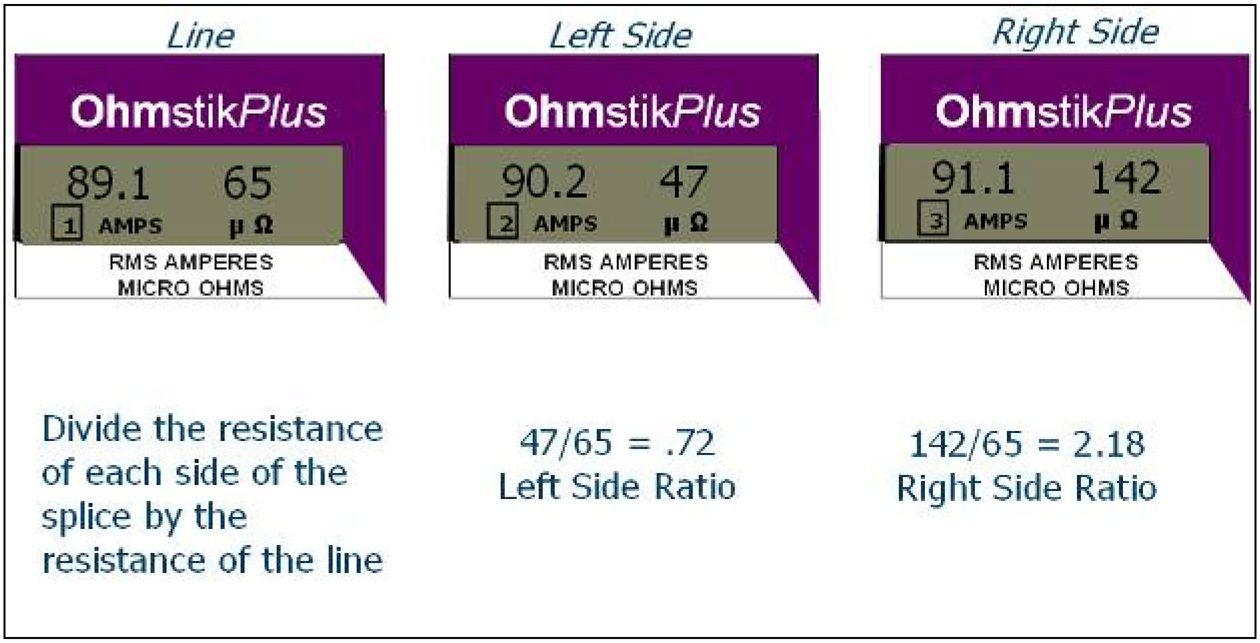


Figure 1 Resistance Calculation Example

Table 4

Resistance Ratio	Action Required
0.3 to 1.0	None - Normal connector
1.01 to 1.2	Level 3
1.21 to 3.0	Level 2
Over 3.1	Level 1

5.0 REPAIR

5.1 Hot Spot Repair Techniques

5.1.1 Insulators

a. Replace

5.1.2 Grounding, Hardware, Shield Wire, Non-current carrying components

a. Evaluate grounding and bonding systems

1. Shall meet present standards

b. Rectify as necessary.

5.1.3 Conductor, Splices, Connectors

a. See Table 5

b. On ACSR conductor ACSS fittings may be used to provide additional electrical contact resulting in a higher quality connection

5.2 Repair Priority / Time Line

5.2.1 Repairs of connectors shall be:

a. Level 1 – Repair within 7 total days

b. Level 2 – Repair within 1 year from date entered into database

c. Level 3 – Repair within 3 years from date entered into database.

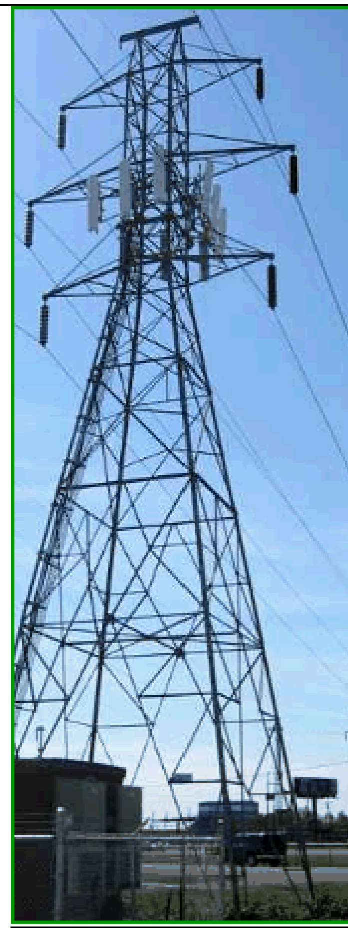
Table 5

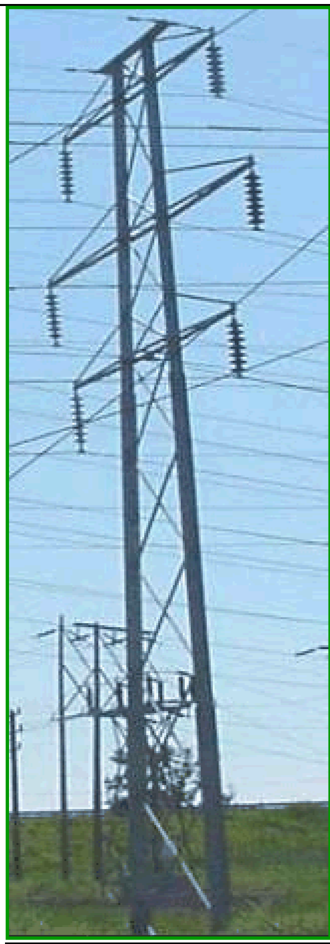
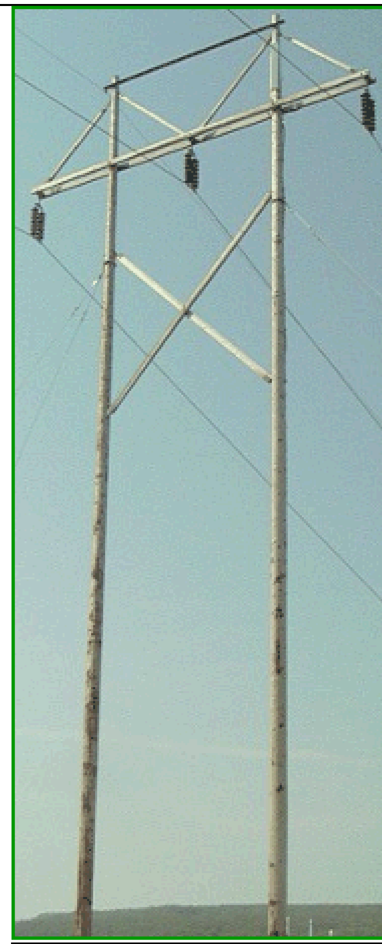
Connector Type	Voltage Class	
	69kV – 230kV	**345kV – 450kV**
Full Tension Splices	Two-die compression (preferred); shunt splice (option)	Two die compression
Jumper Loop Splices	Two die compression (preferred); AMPACT (option)	Two die compression
Compression Deadend	Two-die compression dead-end (preferred); tethered shunt splice (option)	Two-die compression
Quadrant Clamp Deadend	Quadrant Clamp (preferred); two-die compression (option 1); tethered shunt splice (option 2)	N/A
Suspension Clamp	In-kind (preferred), tethered shunt splice (option)	In-kind
Tee Connectors	In-kind	In-kind
Terminal Connectors	In-kind	In-kind

6.0 REVISION HISTORY

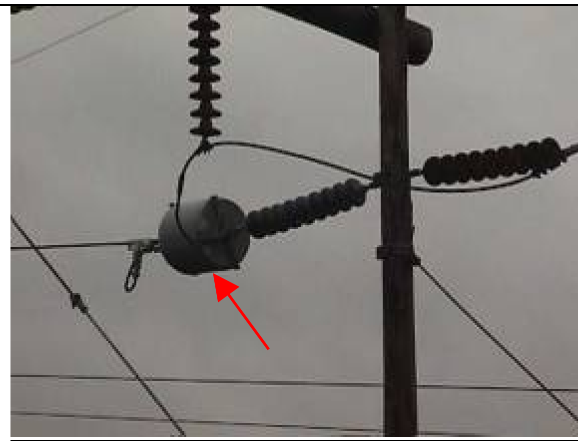
Version	Date	Description of Revision
1.0	06/01/15	This document supersedes PR.06.01.601.003, dated 02/17/11. Put in standard EOP format ; change to outline form; change department names, added Section 5.2.

APPENDIX A – TRANSMISSION LINE COMPONENTS

 **Steel Pole**	 **Steel Lattice Tower**

 **Steel Flex Tower**	 **Wood Pole H-frame**

Riser Structure



Wave Trap

Line Switch

Down Ground

Shield Wire

Crossarm

Insulators

Conductors

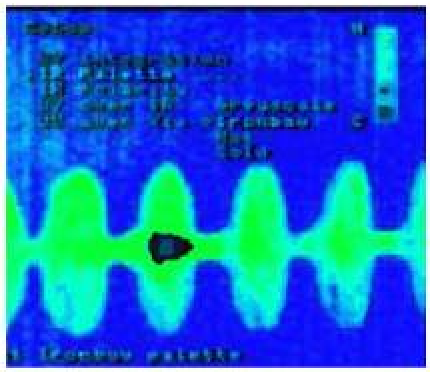
Wood Pole

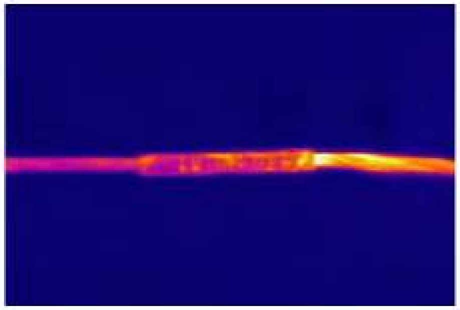
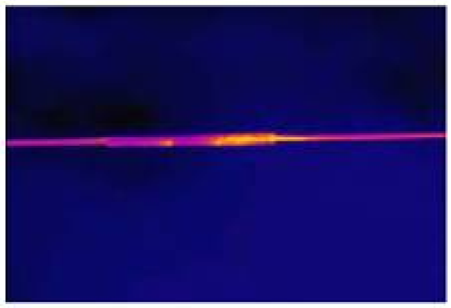
X-brace

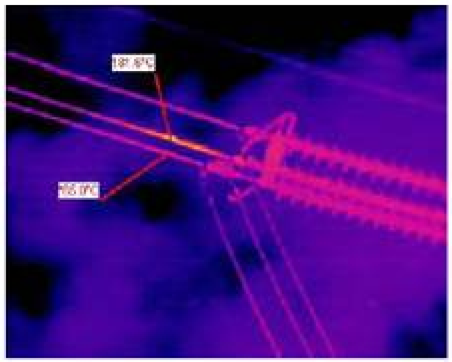
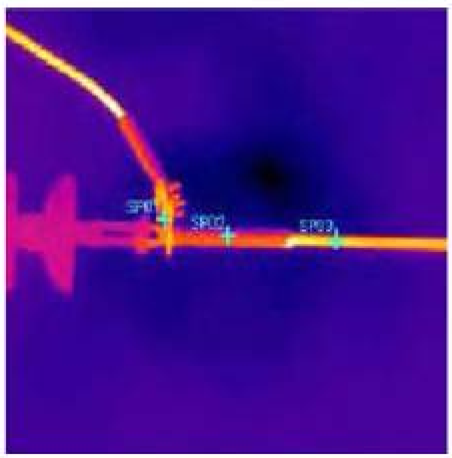
General

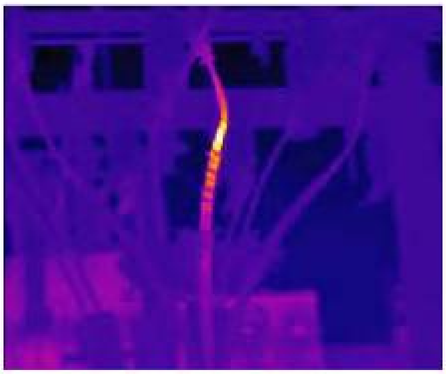
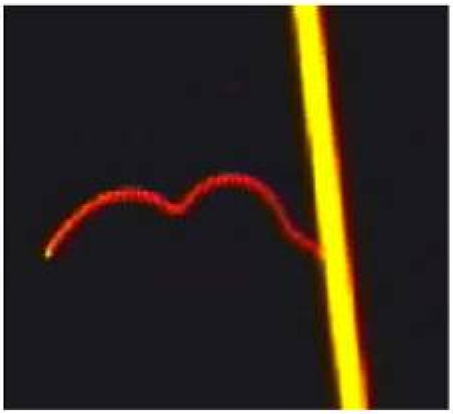
APPENDIX B – COMMON HOT SPOT ISSUES

The following are excerpts from “Overhead Transmission Inspection and Assessment Guidelines” – 2009, Electric Power Research Institute, Table 16-7, Common Transmission Line Components Inspected with IR Technologies.

Component	Condition	Image	Discussion
Polymer Insulator	Increased temperature on insulator core under a shed.		The temperature increase is caused by tracking along the insulator core. In this case the sheath was punctured and the rod exposed to the environment. The IR signature is independent of the transmission line loading.

Splice	Increased temperature at conductor/splice interface	  	An increase in temperature on one or both end of a splice indicates the presence of a bad connection.

Component	Condition	Image	Discussion
Dead End	Temperature increase at conductor/dead-end interface		The conductor end (near the fitting) is much hotter than the rest of the conductor. This is an indication that there is an increase in resistance in this area and therefore increased heating.
	Slight temperature increase at conductor and dead-end/splice interface		This temperature increase is not significant, and no action is required.

Component	Condition	Image	Discussion
Poor grounding	Temperature increase at grounding joint		The increased temperature of this high-resistance joint is due to corrosion or a bad connection.
Contamination	Increased temperature in pin area of bottom insulator		The increase in temperature is caused by dry band arcing at the pin of a contaminated insulator under wetting conditions.
Broken Strand	Loose outer strand		The loose strand is clearly visible as it is cooler than the conductor.

APPENDIX C – HOT SPOT REPORTING WORKSHEET SAMPLE

08/09/2010

Worcester Engineering Laboratory

Thermography Report

nationalgrid

Rec. #: CS100713-3687

Location:
Address:
City: East Longmeadow, MA

Longitude: N 42° 03.456'
Latitude: W 72° 29.770'

Area:
Division: Bay State West
District: Western District
Field Office:
Department: Transmission-NE
Substation:

Inspector: S. Chad
Event Date: 07/13/2010
Event Time: 12:50

Equipment: Air Break Switch

	Celsius (C°)
Absolute Temperature:	65
Reference Temp:	35
Delta Temp:	30

Suggested Action:
Repair within 6 months.

Equipment ID: Air Break Switch # 1485

Structure: -
Circuit: N14
Phase: North West
Voltage: 69

Description: *Jaw of the Air Break Switch # 1485. North - West Phase (Closest to the Tree Line)*

Thermal Image:

Visual Image:

Remarks:

IT2\Production\Default Rpt Project Annual

CBH CHESAPEAKE BAY HELICOPTERS

Thermal Scanning Report

Project/Equipment:	Lockport - Batavia # 112		
Review Contact:	7576412481	Thermographer:	Street
Inspection Date:	06/20/2010	Report Page	1 of 2
	Delta T Rise - C°	5.3	

Procedure as per National Grid EOP T-007	Code	Priority Level	Code*	Temperature Rise**
	4	Green	4	1°-20°C
		Blue	2	21°-40°C
		Red	1	41° - & Above°C
		Call National Grid Rep on any Temp. over 41°C		

Equipment:	Hot spices on top east phase and west phase between structures 193 & 190 US.
Location:	N43.073324° W75.378159° See Video clip Lockport-Batavia#112.20100620.IR.Code4.1446 5.3C E-W for additional details. See attached map
Amperage/Load:	
Probable Cause:	
Remarks:	SP01: 34.3C SP02: 33.7C SP03:28.9 Delta (SP01 & SP03) 5.3C

Note: Notify Thermographer / Specialist after repairs are complete for follow-up Infrared scan.

*Codes	1	Corrective measures should be taken within 5 days - Call National Grid Rep
	2	Corrective measures required within 6 months
	4	Corrective measures - Monitor for change & address accordingly

** delta T rise temperature specs. based on comparison between similar components under similar loading

Procedures per National Grid EOP T-007

APPENDIX D – SHUNT SPLICE INSTALLATION

Shunt splices (ClampStar) can be installed on energized or de-energized lines. All pertinent National Grid work practice procedures should be followed. ClampStar installation is a permanent repair.

Installation procedure for the Clamp Star shunt splice

1. Locations where shunt splices are installed shall be forwarded to T&D Maintenance or Electric Operations for tracking
2. Tethered shunt splices required at dead-ends
3. Before shunt splice application, the defective section to be spliced shall be examined for integrity so the added weight of the shunt splice will not cause mechanical failure.
4. Thoroughly brush conductor where the shunt splice unit will be attached to remove oxidation and contaminant residues. ClampStar units are factory loaded with inhibitor, no additional inhibitor is required.
5. Open clamps on the ClampStar unit wide enough so that the ClampStar will fit on the conductor.
6. Position ClampStar over the splice as shown in Figure 2 below. Some conductor length should be present between the ClampStar unit and existing splice. It is not necessary to center the ClampStar unit over the splice.

Figure 2 Rigid ClampStar Shunt Splice unit

7. Nuts should be snugged first, starting from the center of the ClampStar unit and working outward. Nuts should be moderately tightened during a second pass again from center outward, followed by a third pass which should snap off the torque nuts.
8. ClampStars are supplied with torque limiting nuts designed to snap off during installation. The smallest ClampStar nuts are designed to shear off at 25 foot-lbs, while the largest ClampStar nuts require 40 to 45 foot-lbs of torque. (Figure 3)

Figure 3 Torque nuts on the ClampStar shunt splice unit

9. ClampStar units at deadend and suspension clamp locations shall be installed in the same manner as full tension splice locations. Deadend and suspension clamp installation shall also be fitted with a safety tether (See Figure 4 and 5).

Figure 4 Tethered Flexible ClampStar Installation

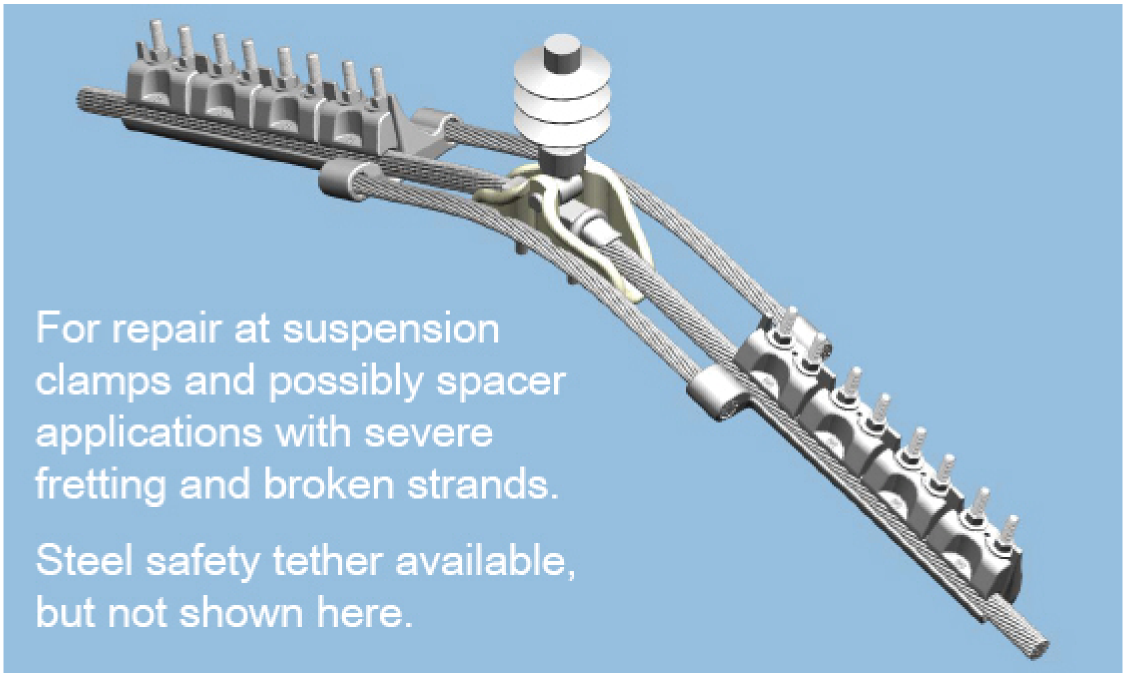


Figure 5 Flexible ClampStar shunt splice unit installed over a suspension clamp location