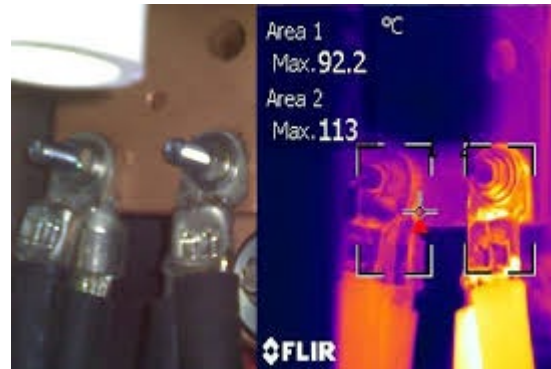


# NSRP 2023 Panel Project 2019-477-04 DTS Integration into Electrical Plant Controls for Conditions Based Maintenance

## FINAL REPORT

April 3, 2024

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RSL Fiber Systems, LLC



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# NSRP PROJECT EVOLUTION

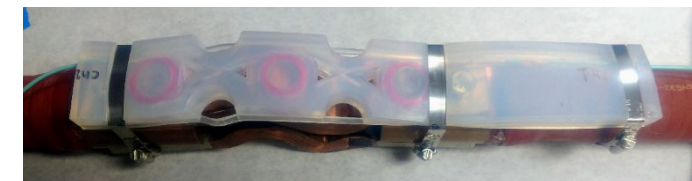
## Inspection of MV and HV Electrical Assets

### OBJECTIVES:

- Prevent damage due to loosened connections (arcing).
- Reduce risk to personnel.
- Reduce maintenance costs.
- **Perform Condition Based Maintenance (CBM).**



- **2015 – PSU EOC**, HII-Ingalls, SUPSHIP GC: Reduce risk of inspection of MV Electrical panels by use of windows for IR thermal imaging.
- **2015 – RSL Fiber Systems** presents fiber optic Raman DTS at NSRP Electrical Technologies Panel mtg (San Diego).
- **2017 – PSU EOC**, HII-Ingalls, SUPSHIP GC: Evaluation of DTS for monitoring MV electrical panels.
- **2019\*** – **Hepburn & Sons**, RSL FS: Raman DTS to monitor connections of Insulated Bus Pipe (IBP).
- **2020\*** – **Hepburn & Sons**, RSL FS: Raman DTS to monitor IBP connections to equipment.
- **2023 – RSL Fiber Systems**, NAVSEA 05Z33, NSWC PD, BIW, PSU EOC: DTS Integration into Electrical Plant Controls.



\* NSRP Research Announcements

# 2023 NSRP PANEL PROJECT

## DTS Integration into Electrical Plant Controls

Project 2019-477-004

***Detect → Isolate → Determine Severity → Define Action***

Monitor temperature of connections in U.S. Navy ships' Medium Voltage (MV = 4,160 VAC) electrical panels in real time to detect loosening connections and prevent arc flashing by collecting and providing actionable data.

### TASKS

1. Methodology to secure the fiber optic sensors to the electrical connections.
2. Configure the GUI to display actionable Condition Based Maintenance data collected by the DTS.
3. Create baseline guidelines and specifications to qualify and implement DTS on Navy vessels.
4. Provide baseline for project to finalize development and qualify DTS system for MV panels monitoring.

## TEAM MEMBERS

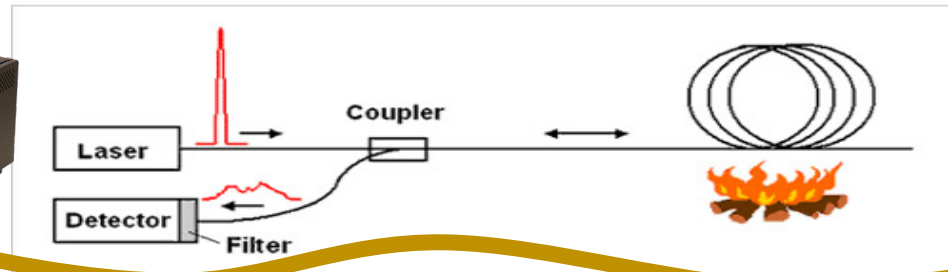
- Prime/Lead: RSL Fiber Systems, LLC
- Team Members: Penn State University – ARL, General Dynamics – Bath Iron Works, DV7 Engineering, Silixa, NAVSEA 05Z33, NSWCPD.
- Program Technical Representative: Jason Farmer, Ingalls Shipbuilding.

## ROI

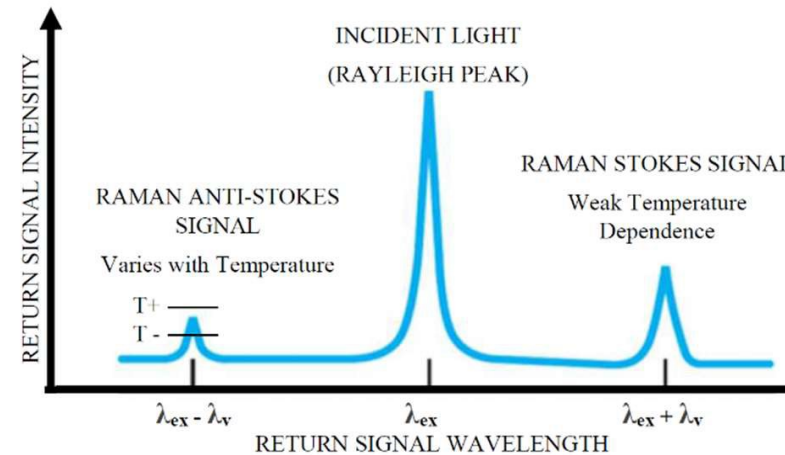
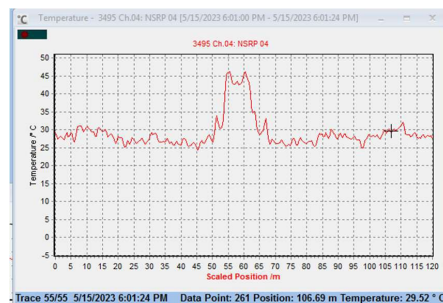
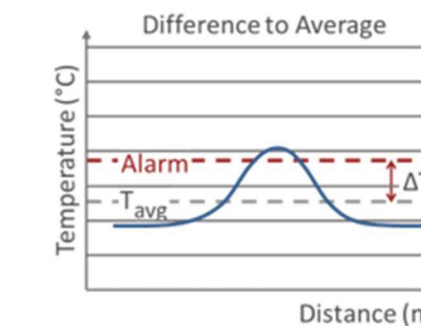
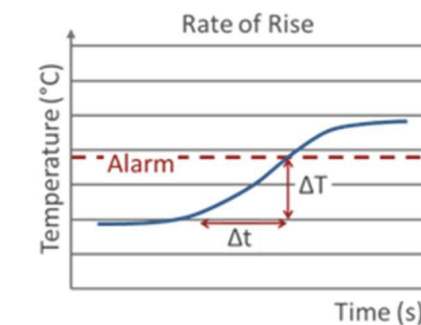
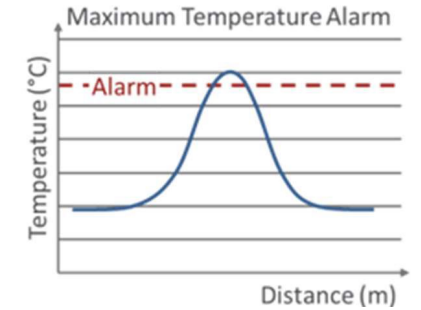
- **Reduce labor costs** by eliminating the need to perform thermal imaging and troubleshooting on energized panels.
- **Eliminate the safety hazards** involved in visually inspecting energized electrical panels.
- **Eliminate the risk of fire** and conductors' damage resulting from loose electrical connections.
- Constant monitoring of bolted connection temperatures will alert to early occurrence, **prevent unexpected failures**, reduce troubleshooting time and eliminate the need to make temperature measurements on an energized panel.

**CONTRACT CLOSING DATE:** April 8, 2024

# Fiber Optic Distributed Temperature Sensing

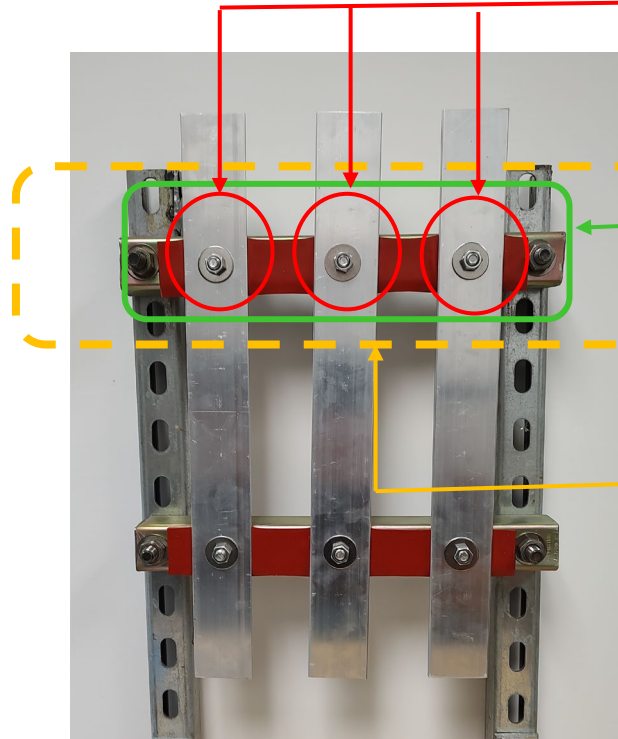


- **Entire fiber is the sensing unit** – up to 10,000 programmable zones per fiber channel.
- Zones can overlap and encompass multiple zones.
- Multiple warnings / alarms can be set in each zone.
- Standard MM 50/125, 62.5/125 or SM fiber.
- Up to 30 Km MM, 40 Km SM - real time monitoring across entire length.
- Temperature rise of 0.1°C
- Spatial Resolution down to 50 cm.
- Based on Raman Scattering.





# EXAMPLE – DEMO OF 3 PH. PANEL



**Zones 1, 2, 3: Individual Connections**

Temperature of Each Connection (T)  
Rate of Temperature Change ( $\Delta T/\Delta t$ )

**Zone 4: Three Phase Busbars (3)**

Difference in Temperature between Three Connections ( $\Delta T$ )

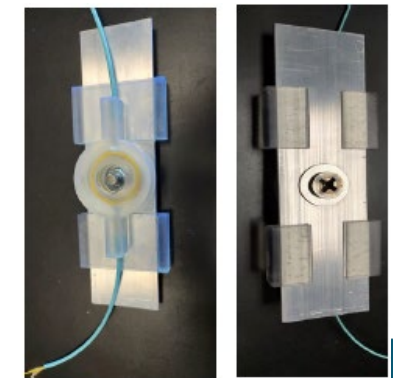
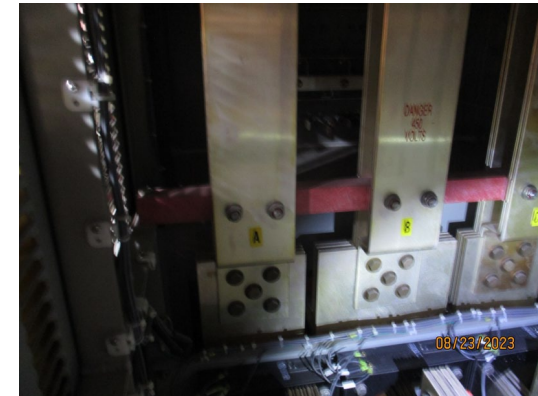
**Zone 5: Entire Panel (all Busbars + Connections)**

Temperature within entire Panel (T)  
Difference in Temperature ( $\Delta T$ )  
Rate of Temperature Change ( $\Delta T/\Delta t$ )

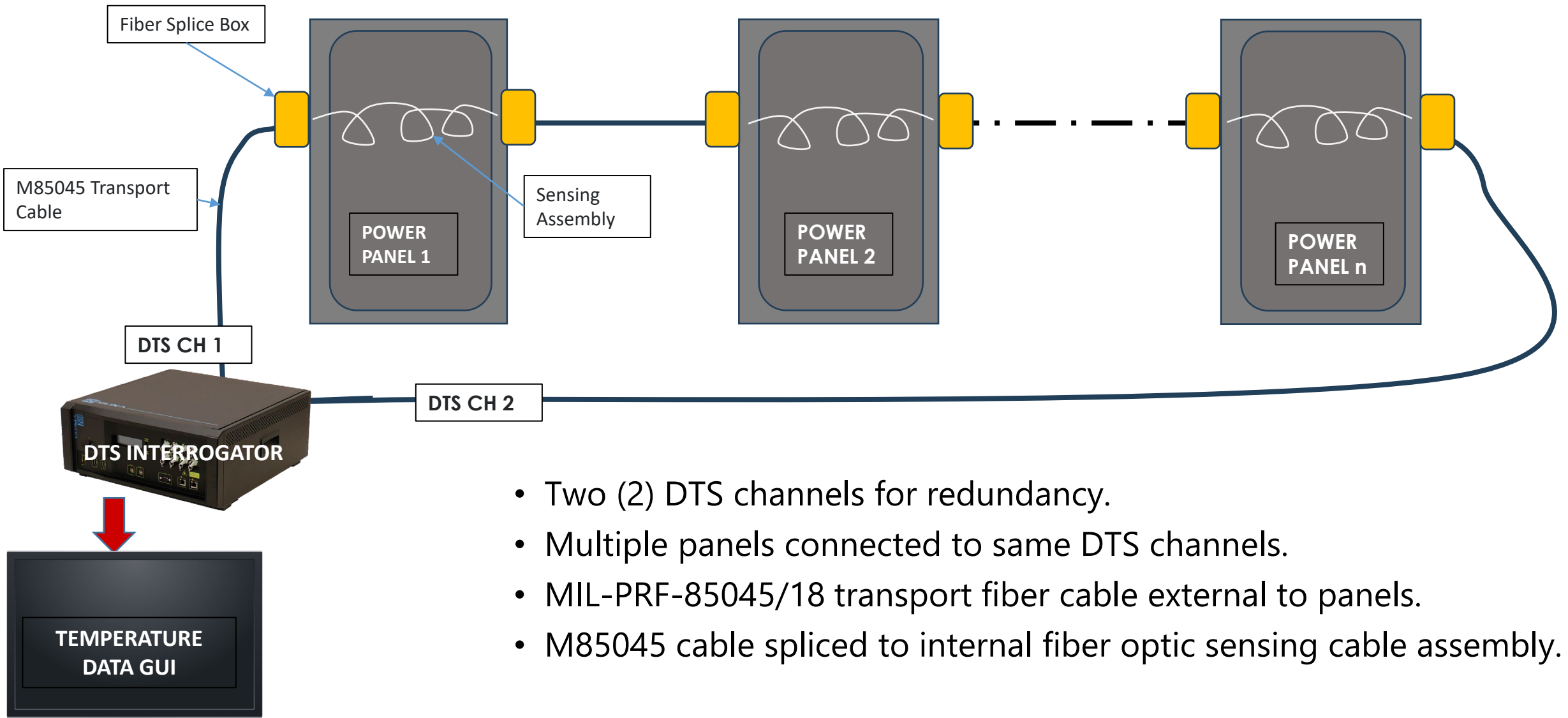
ZONE #	ZONE NAME	START	END	MONITORING	Pre-Alarm @ Temp	Alarm @ Temp
1	Connection 1	76.7	78.7	Min & Max T, $\Delta T/\Delta t$	> 50°C & $\Delta T/\Delta t > 5/60$	> 80°C & < 10°C
2	Connection 2	71.6	73.6	Min & Max T, $\Delta T/\Delta t$	> 50°C & $\Delta T/\Delta t > 5/60$	> 80°C & < 10°C
3	Connection 3	66.2	68.7	Min & Max T, $\Delta T/\Delta t$	> 50°C & $\Delta T/\Delta t > 5/60$	> 80°C & < 10°C
4	Busbars 1-2-3	66.2	78.7	$\Delta T$ between C1, C2, and C3	$\Delta > 10^\circ\text{C}$	$\Delta > 25^\circ\text{C}$
5	Full Panel	20	120	T, $\Delta T$ , $\Delta T/\Delta t$ in Panel	> 50°C, > 5/60, & $\Delta > 10^\circ\text{C}$	> 80°C, > 10/60, & $\Delta > 25^\circ\text{C}$

# DTS PROJECT UPDATE

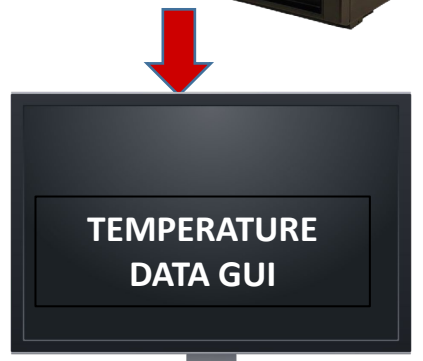
- Three (3) Hands-On System Demonstrations + one (1) On Ship Visit.
  - Use a **dedicated processor & display** not connected to the shipboard network to simplify cybersecurity requirements.
  - **LV panels (450 VAC)** also candidate for DTS → many on ships w/ faults most common.
  - Pre-installed fiber sensing assemblies may get damaged when installing power cables.
    - **Install assemblies after power cables.**
  - Metal straps used in the IBP may cause arcing in MV and HV panels.
    - Use molded assemblies' shapes to **attach without straps.**
    - Use materials **for 90°C Max normal operation and 120°C Max excursions.**
    - Data from NSRP 2019-477-03 Cable Jacket Panel Project to identify materials.
- Developed outline for Graphical User Interface.
- Developed outline for DTS Implementation → system **configuration, installation, commissioning, and maintenance.**
- Planning **System demo at DDG 51 land test site** after project close.



# DTS – BASELINE SYSTEM CONFIGURATION



- Two (2) DTS channels for redundancy.
- Multiple panels connected to same DTS channels.
- MIL-PRF-85045/18 transport fiber cable external to panels.
- M85045 cable spliced to internal fiber optic sensing cable assembly.





# DTS IMPLEMENTATION

## 1 - INTERROGATOR CONFIGURATION

### DATA COLLECTION

- Define temperature sampling rates.
- Set data retention requirements for data analytics.

### DATA DISPLAY

- Set warnings and alarms.
- Configure HMI / GUI for Actionable information.
- Provide "Maintenance" option for systems check.

## 2 - INSTALLATION

### FIBER OPTIC ASSEMBLIES

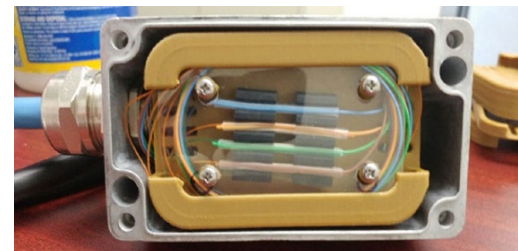
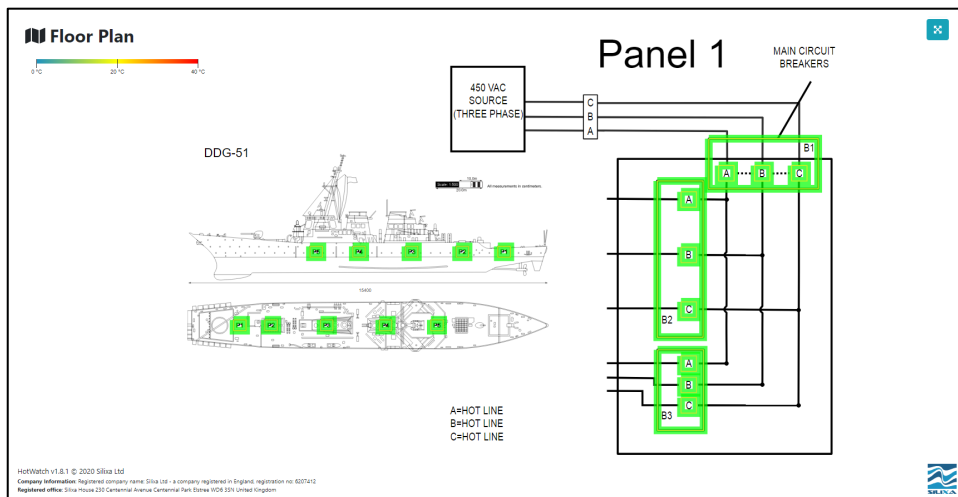
- Connections / zones configuration management.
- Assembly P/N based on panel type.
- Fiber cable assemblies' installation procedure.
- Fusion splicing connections to external fiber optic cable.

### DTS INTERROGATOR

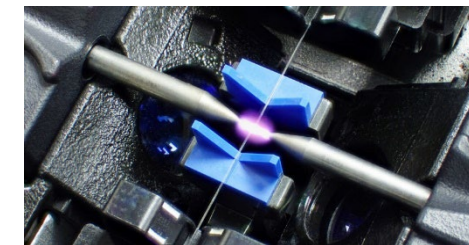
- Interrogator and GUI / HMI device location.

### TRANSPORT FIBER OPTIC CABLE

- Cable routing.
- Splicing fiber pigtails for connection to DTS interrogator.



2019 PSU EOC NSRP Panel Project:  
Fusion Splice Enclosure at Equipment



2021 HII – Ingalls NSRP Panel Project: Evaluation of Splice-On Connectors and Termini for Shipboard Applications

# DTS IMPLEMENTATION

## 3 - SYSTEM COMMISSIONING

### ZONES IDENTIFICATION

- Identification methodology of panels and sensing zones.
- Verification of correct attachment for sensing assemblies.

### SYSTEM ACCEPTANCE TEST

- Run system acceptance testing procedure with OTDR.
- Verify correct temperature detection.



2019 Kitco Panel Project  
Fiber Optic Testing Enhancement for Cost Reduction

## 4 - IN-SERVICE OPERATIONS

### MAINTENANCE

- Interrogate system for maintenance.
- Verify system integrity.
- Data Analytics for CBM definition.

### FIELD REPAIRS

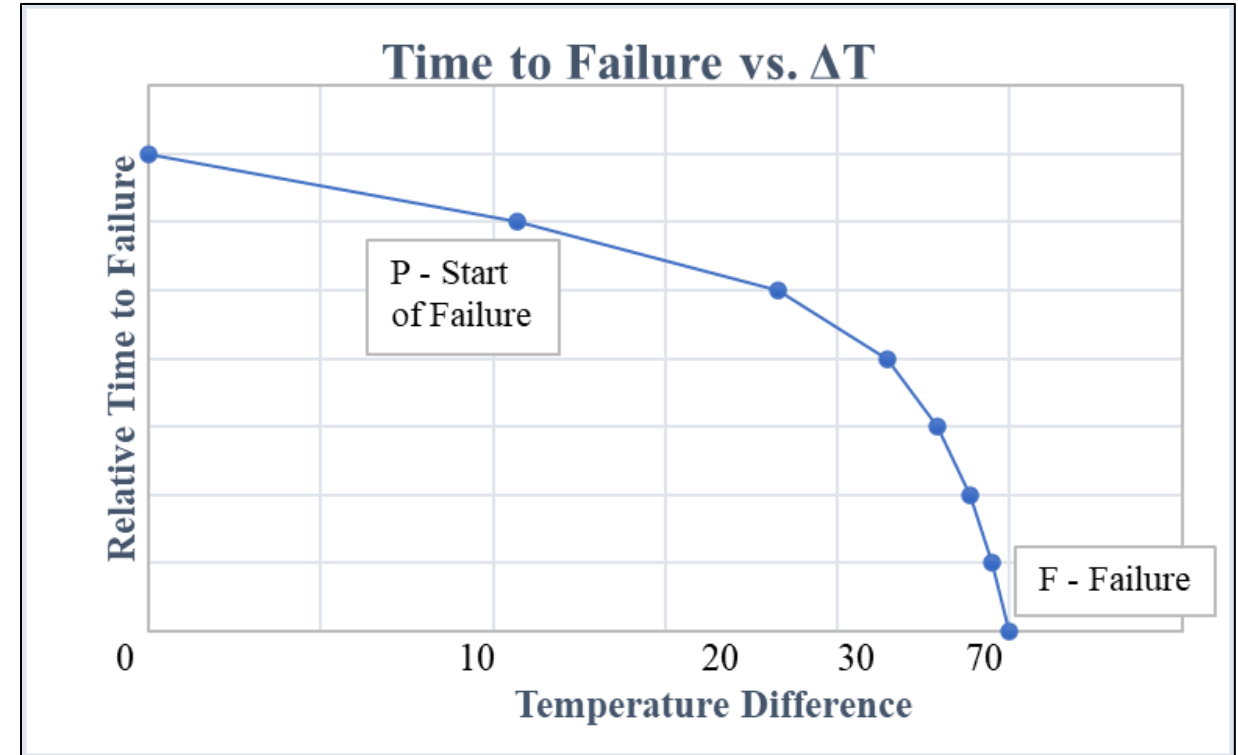
- Field repairs of assemblies.
- Reconfiguration process for sensing zones if cables cut / damaged.
- Capability for the addition of new panels or sensing zones.

# DTS DATA ANALYTICS

## CONDITION BASED MAINTENANCE

Define Prevention – Failure (P-F) curve for LV, MV, and HV electrical panels from data collected by DTS controller.

Priority	Temp Rise or $\Delta T$	Operational Assessment	Severity Code	Action
1	$\geq 70^{\circ}\text{C}$	Failure Imminent	****	Equipment should be secured immediately and not operated until repairs are complete.
2	$40^{\circ}\text{C}$ to $< 70^{\circ}\text{C}$	Failure Almost Certain	***	Equipment should be secured if operating conditions permit otherwise monitored until corrective action can be taken.
3	$20^{\circ}\text{C}$ to $< 40^{\circ}\text{C}$	Failure Possible	**	Corrective action should be taken as soon as feasible.
4	$5^{\circ}\text{C}$ to $< 20^{\circ}\text{C}$	Performance Degraded	*	Corrective action should be taken at next scheduled routine maintenance period or as schedule permits.
	$< 5^{\circ}\text{C}$	N/A	N/A	No corrective action required; note for future reference.



NOTE: Graph for illustrative purpose only. Not based on actual data.

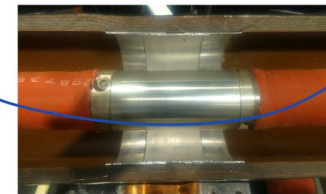
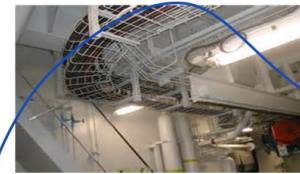
Table from MIL-STD-2194\*

(\*) Obsolete but same table used in other MIL STD documents.

# TECHNOLOGY TRANSFER

- Presented at **MFPT 2023**  
[Co-Authors: G. Tomasi, C. Nemarich]
- Presented at **SNAME SMC 2023**  
[Co-Authors: G. Tomasi, C. Nemarich and R. DeLoge]
- Presented at **ShipTech 2024**  
[Co-Authors: G. Tomasi, C. Nemarich and R. DeLoge]
- Paper to be Published in **ASNE Journal**  
[Co-Authors: G. Tomasi, C. Nemarich, B. Whaley, and R. DeLoge]
- *Follow-on 2025 NSRP Panel Project proposal to **investigate other applications** for DTS.*

## DTS – SHIPBOARD APPLICATIONS



Data Displayed

- LV, MV, and HV electrical panels monitoring
- Insulated Bus Pipe Connections
- **FIRE DETECTION**
- Machinery health monitoring
- Cabling systems health monitoring
- Food storage spaces
- Others...
- **Single DTS and single cable for multiple functions**



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# TECHNOLOGY TRANSFER

- *NSWCPD (B. Whaley) drafting Baseline for **Ship Change Document (SCD) Temp Alt** to install DTS on in-service ship.*





# QUESTIONS?

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