Incident Summary #II-1487206-2022 (#30819) (FINAL)

Section			Field	Details
SUPPORTING INFORMATION	Incident Date			December 28, 2022
	Location			Armstrong
	Regulated industry sector			Electrical - High voltage electrical system (greater than 750 V)
	Impact	Injury	Qty injuries	0
			Injury description	N/A
			Injury rating	None
		Damage	Damage description	A 6 section 25 kilovolt (kV) indoor, high voltage, metal-clad switchgear unit had 2 modules destroyed by a fault that started a small fire within the structure. The fault also permanently damaged an outdoor 10-15 megavolt ampere (MVA) 138 kV - 25 kV pad mount transformer in the switchyard. The damage resulted in significant downtime for the facility.
			Damage rating	Severe
	Incident rating			Severe
	Incident overview			A high voltage electrical fault occurred at an industrial lumber mill and plywood plant. The fault occurred inside an indoor 25 kV metal-clad switchgear enclosure. The overcurrent protection of the primary voltage system was a circuit breaker located upstream on the 138 kV primary line. The breaker was in a locked condition and failed to open after a fault, allowing high current to continue and damage the downstream switchgear. The fault continued to occur for an extended timeframe of approximately 3 minutes duration before it tripped the utility transmission line overload that de-energized power distribution to the facility and a large surrounding area.
INVESTIGATION CONCLUSIONS	Site, system and components			The 138 kV high voltage switchyard is located within a specific and dedicated fenced in area on the site and is connected to the utilities 138 kV 3-phase transmission line. Consumer owned equipment located within this area transforms the 138 kV power to 25 kV power which is distributed throughout the operational site via 25kv switchgear. Each individual sub-feeder is provided with overcurrent protection rated for each location. The site equipment includes: • An outdoor 138 kV- 25 kV 3-phase pad mounted transformer reduces the voltage to allow 25 kV switchgear located in a dedicated structure to distribute power to various operations throughout the site to operate the plywood plant, chipper mill, and the sawmill. • Within the 138 kV portion in the switchyard, there were surge arrestors to protect connected equipment located on both line and load connections of the utility high voltage metering equipment. • A power monitoring/ protection control system was installed within the past 2-3 years that was designed to monitor/ protect the operating equipment. • Additional unit sub-stations are located at other facilities that further reduce power as required to operate the facilities. • A non-load rated air-break disconnect in combination with an SF-6 138 kV rated, gas insulated load break rated breaker is utilized for overcurrent and disconnecting means. The unit is filled with SF6 gas as an insulating medium. The gas is needed to interrupt an electrical arc when the contacts are opened. Without an insulating medium, a high voltage electrical arc may be sustained that could destroy the switch.

	The normal operating gas pressure at 20ºC is 87 psi, the minimum required gas pressure at 20ºC is 72 psi. The monitoring alarm is set to trip at 76 psi and the unit will go into a lockout state under 72 psi. The unit is designed to lockout under this pressure and will not permit the breaker to trip to protect the switch if it receives a signal to open. **Stress Cones:** There are various types of stress cones used that all utilize the same principles to eliminate dielectric stress concentration to avoid breakdown of a cable (Photo16). There is a large concentration of electric flux lines at the point where the shield ends and the conductor itself. If there is no stress cone installed, these lines will create a large concentration of the electric field and heating, which can damage the dielectric strength of the insulation and cause the cable to fail. Properly installed stress cones will spread out the flux lines along the connection and relieve the fitting of unwanted heating and cable failure. **Arc flash characteristics:** • Arc flashes can occur when an energized conductor is shorted (makes contact) to another energized conductor or to grounded metal. The severity of the arc flash is dependant on the available voltage and current as well as the time it takes the overcurrent protection to clear the fault. • During an arc flash the air surrounding the arcing components may become ionized and conduct electricity, like a lightning strike, increasing the distance and range of damage and potential injuries. • Arc flashes can release vaporized metal, extreme heat, light, sound, and pressure from the electrical equipment. The arc flash can cause severe burns as well as hearing and vision damage to people in the area. • Metal such as copper bus bars can be melted by the arc flash and may increase up to 67,000 times the original size while vaporizing and exploding out. • The arc flash can reach temperatures up to 20,000ºC. • The volumetric expansion can reach 40,000- 67,000 times.
Failure scenario(s)	The high voltage electrical substation equipment for the facility was originally designed, engineered, and constructed in 1994. The system received an upgrade in January 2022 to the 138kV protection relays and the installation of remote monitoring of the components within the 138kV and 25kV systems. • December 3, 2022 - During a cold weather period with temperature lows of -13ºC, the SF6 insulating gas pressure in the 138kV breaker fell below 76psi and the monitoring system sent out a "low gas pressure" alarm. A contractor responded to the alarm and topped up the gas. • December 22, 2022 - During another extreme cold weather period with temperature lows of -30ºC, the gas pressure in the 138kV breaker dropped below 76 psi again and the monitoring system sent out another "low gas pressure" alarm. This time the gas was not topped back up and the breaker was left in that state. The gas pressure dropped below the operating limit of 72 psi and the breaker entered a locked-out mode that would not allow the switch to open from a trip signal. • December 28, 2022, 4:07 AM - A failure occurred on the load side of the Sawmill vacuum breaker on a 'Stress Cone' in Phase 'C' within the back cavity of the enclosure. The fault in the cable created an arc flash and a fault occurred within module #6.

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	The 25 kV primary main disconnecting means in the switchgear did not include any overcurrent protection. The only overcurrent protection provided was on the line side of the 138 kV – 25 kV transformer with use of an SF-6 138 kV breaker. The 138 kV SF-6 breaker was in a locked condition due to low gas pressure and the fault was not de-energized due to the state. No other overcurrent protection was in place to de-energize the system from the utility connections within the switchgear. The 138kV breaker is designed to de-energize the downstream system in less than a second but due to it being in lock-out mode the fault continued for 165 seconds until the upstream utility protection devices tripped, disconnecting power to the facility and a large surrounding area.
Facts and evidence	<u>Facility staff and contractor statements</u> • At the time of the incident, milling and plywood production operations were shut down for the vacation season and due to market conditions. The only electrical loads powered at the time were the heating, lighting, and ancillary equipment associated with the production facilities. **SF-6 Breaker** • The breaker has ability to trip via monitoring/protection equipment installed when in a normal operating condition, (The device does not have any internal tripping overcurrent settings but rather is rated max 1200 amp continuous current). • Investigation on what can affect gas pressure loss included operating in very low temperatures as the seals can shrink, the temperatures within the week leading to incident included lows of -13 C and down to -34 C on date of incident. • The insulating gas is used to extinguish the arcing within the breaker when operating, without minimum gas pressure, the breaker would be susceptible to major equipment failure. • Dec 3, 2022, the SF6 insulating gas was topped up by the contractor due to low gas pressure alarm notification. The gas was topped up to a normal operating pressure 87 psig. • Dec 22, 2022, the low gas pressure notification was sent once again @76psig, and no action was taken. • The gas pressure further reduced to below 72 psi and the breaker entered ‘lock out” mode that prevented it from operating. • A trip signal was provided during the incident, but the breaker did not trip due to the lock out feature. **MVA transformer** • The winding temperature gauge reached 140 Celsius. • The oil thermometer temperature gauge read approx. 108 Celsius. • The pressure relief released and blew out oil onto the ground. • Alarms were noted in monitoring system. **25kV metal-clad switchgear** • It was originally installed in 1994. • The main disconnecting switch had no overcurrent protection, it had load break capabilities only. • Module #1 was a main disconnect, Module #2 was not in use for 25 kV (low voltage 120/240 volt panel board installed), Module #3 was the ‘original’ Plywood Plant load break switch with 600 amp 25 kV fusing, Module #4 was not in use, Module #5 was the sawmill with disconnect / Current transformers

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(CT's), and vacuum breaker feeder protection relay equipment, Module #6 was the chip plant with disconnect, CT's and vacuum breaker feeder protection relay equipment.

- The system is constructed of a metal enclosure with bare horizontal buss-bar system connecting 6 modules approx. 48" wide for each section.
- Individual vertical bussing is tapped off within each module to provide tap power as required.
- Openings between the 25 kV buss-bar area in the 6 modules are very large with no insulating barriers to separate the compartments.
- Spacing from the metal enclosure was found tightest within last enclosure with horizontal bussing as close as approximately 7" from metal enclosure, which the high voltage Contractor stated were compliant but tight for clearance requirements.

Monitoring/Control equipment.

- SEL-751 Feeder Protection Relays were installed for the main 138 kV breaker, Sawmill and Chip Plant feeders. The plywood plant was not done at the time of the incident.
- SEL-787 Transformer Protection relay was installed for the 138 kV – 25 kV transformer.
- A digital monitoring system was installed to monitor various requirements that included volts/ amps, frequency, overload, ground fault, transformer primary/ secondary differential readings.
- Alarms/ warning lights were for: SF-6 Breaker: low gas, spring discharged, breaker open/ closed, Transformer: sudden pressure drop, Winding Temperature.

Documentation of logged events timeline

- 07:49:34 AM - Sawmill noted phase C to ground fault and within 49.855mS the breaker tripped.
  138 kV = n/a, 25 kV = 3500-amp peak
- 07:51:16 AM - SF6 breaker overcurrent pickup
  138 kV= 600-amp peak, 25 kV = 3312-amp peak
- 07:51:84 AM - SF6 breaker overcurrent trip (Did not operate)
  138 kV = 600-amp peak, 25 kV = 3312-amp peak
- 07:52:82 AM - Transformer winding 1 overcurrent trip.
  138 kV = 600-amp peak, 25 kV = 3312-amp peak
- 09:36:73 AM - Transformer differential trip
  138 kV = 600-amp peak, 25 kV = 3500-amp peak
- 10:35:03 AM - 138kV SF-6 breaker, Instantaneous overcurrent, and ground fault trip- (Did not operate)
  138 kV = 7500-amps peak, 25 kV = no reading noted
- 10:43:00 AM - Electrical utility trip

**Utility automatic reclosers tried 2 times to re-energize the lines and failed on both attempts prior to locking out.*

Onsite investigation found a stress cone on 25 kV phase C (load side of vacuum breaker) that had a noted fault in the connection (Photo 13-15), a clear hole was noted from the interior conductor through the insulating material and shorting to the semi-conductors shield with the bonding shield. They noted as being typical for a fault from the inside blown outwards.

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Causes and contributing factors	The cause of the incident was the breakdown and failure of the cable stress cone on the phase C cable. The extreme cold weather may have contributed to the low gas pressure in the 138 kV breaker. The failure to repair the low gas pressure in the 138 kV breaker was a contributing factor to the incident by allowing it to not disconnect power and allowing the fault to continue for up to 3 minutes which greatly increasing the amount of damage which resulted.

Photo 1 - 138 kV SF-6 main overcurrent breaker, first and only overcurrent protection prior to the switchgear disconnects, Breaker was in 'lock out mode' due to insufficient gas pressure.

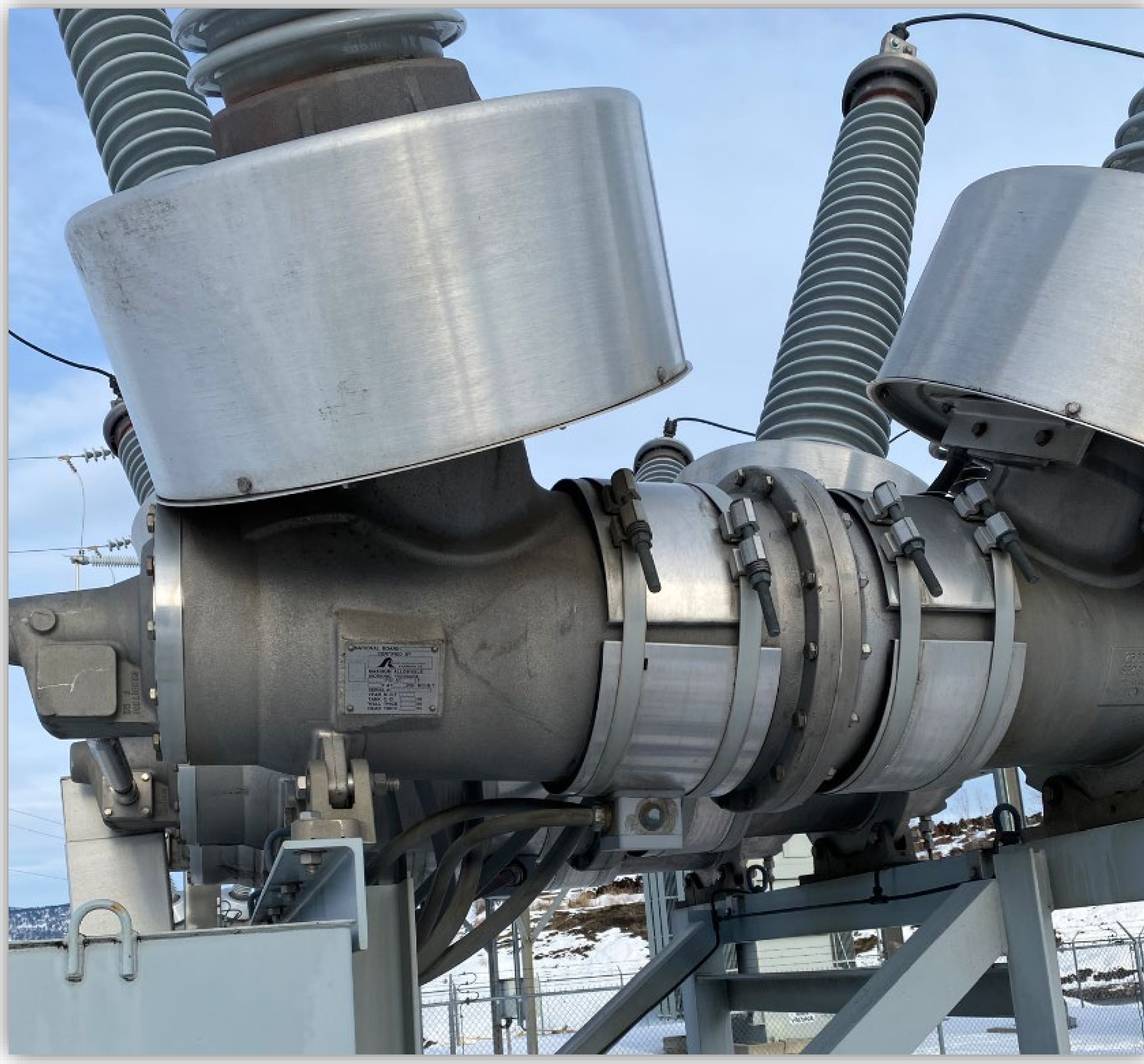


Photo 2 - Close up view of SF-6 breaker equipment with electric heating bands.

Photo 3 - SF-6 breaker gas pressure at time of assessment at 50 psi. Low Pressure alarm is triggered at 76 psi and breaker lock-out mode is 72 psi preventing breaker from operating.

Photo 4 - 138-25 kV transformer showing oil spillage on ground.

Photo 5 - Transformer control cabinet with gauges.

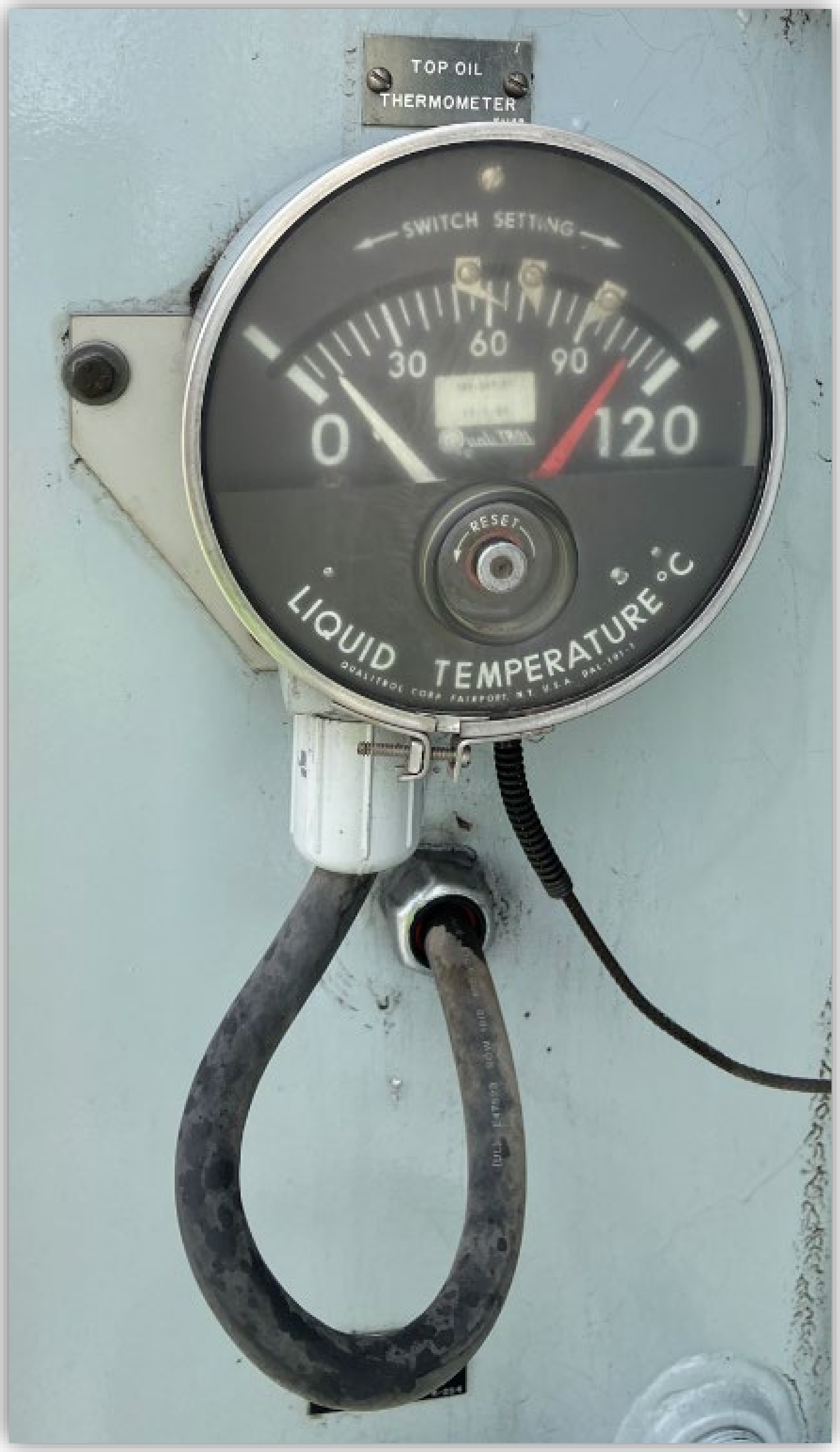


Photo 6 – Transformer oil temperature gauge with red indicator showing oil temperature reached nearing 110 degrees Celsius.

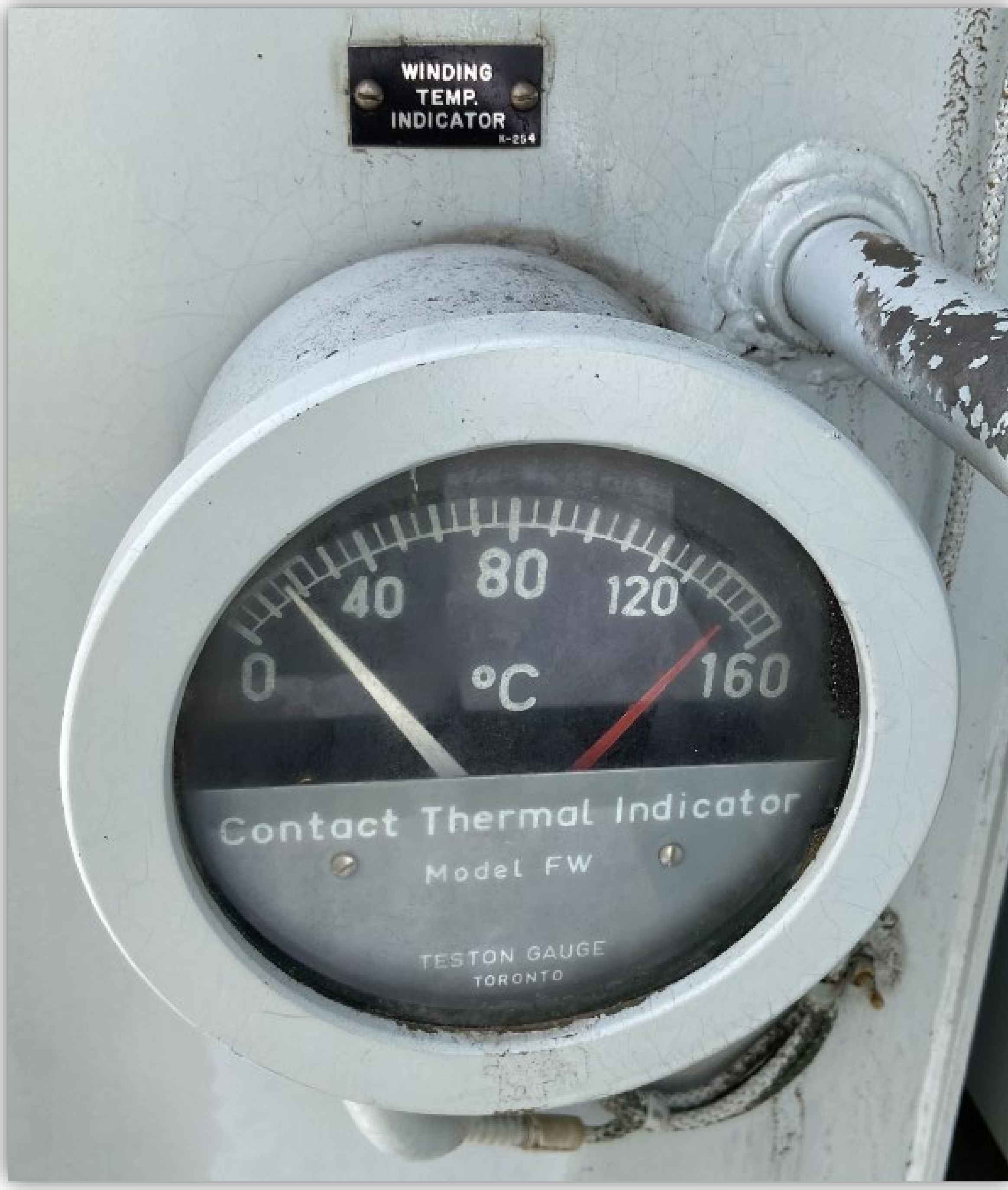


Photo 7 - Transformer winding temperature gauge with red indicator showing winding temperature reached 145+ degrees Celsius.

Relay	Dec 28th Time	Element	Event	138kV Primary Current (A Peak)	25kV Secondary Current (A Peak)
Sawmill SEL751	04:07:49.34	50/51T	Inst & Time **TRIP**		3500
Main SEL751	04:07:51.16	51P1P	Time Over Current Pickup	600	3312
Main SEL751	04:07:51.84	51P1T	Time Over Current **TRIP**	600	3312
Main SEL787	04:07:52.82	51P1T	Winding 1 TOC **TRIP**	600	3312
Main SEL787	04:09:36.73	87R, TRXFMR	Transformer Differential **TRIP**	600	3500
Main SEL751	04:10:35.03	50/51P1T, 50/51G1T	INST/ TOC **TRIP**, Ground Fault **TRIP**	7500	
BCH VNT/ SAM	04:10:43.00	21 or 50G/51G	BC Hydro **TRIP**		
Main SEL751	04:11:05.27	50/51P1T, 50/51G1T	INST/ TOC **TRIP,** Ground Fault **TRIP**	4600	
Main SEL787	04:11:05.89	87R, 87U, TRXFMR	Transformer Differential **TRIP**	4500	0
BCH VNT/ SAM	04:11:15.00	22 or 50G/51G	BC Hydro Automatic Reclose & Immediate **TRIP** (1st Attempt)		
Main SEL751	04:20:35.36	50/51P1T, 50/51G1T	INST/ TOC **TRIP,** Ground Fault **TRIP**	6000	
Main SEL787	04:20:35.99	87R, 87U, TRXFMR	Transformer Differential **TRIP**	4600	0
BCH VNT	04:20:43.00	23 or 50G/51G	BC Hydro Manual Reclose & Immediate **TRIP** (2nd Attempt, RVS/ RVG only)		
Main SEL751	04:22:06.26	50/51P1T, 50/51G1T	INST/ TOC **TRIP,** Ground Fault **TRIP**	4500	
Main SEL787	04:22:06.89	87R, 87U, TRXFMR	Transformer Differential **TRIP**	4200	0
BCH VNT	??????		RVG power back online		

Table 1- Relay Event Timeline

Photo 8 - Timeline of events retrieved from protection relays and real time recorder. Sawmill SEL751 is on sawmill disconnect, Main SEL751 is main 138 kV breaker, Transformer SEL787 is on 138-25 kV transformer.

Photo 9 - Front view of 25kV switchgear, module closest is #6- chip mill where majority of damage occurred in the back of the unit, next unit is #5 where initial stress cone fault occurred in the back of the unit.

Photo 10 - End section of Unit #6 chip mill where majority of damage occurred, back side of unit has large hole approx. 2’w x6’ high blown through it.

TECHNICAL SAFETY BC

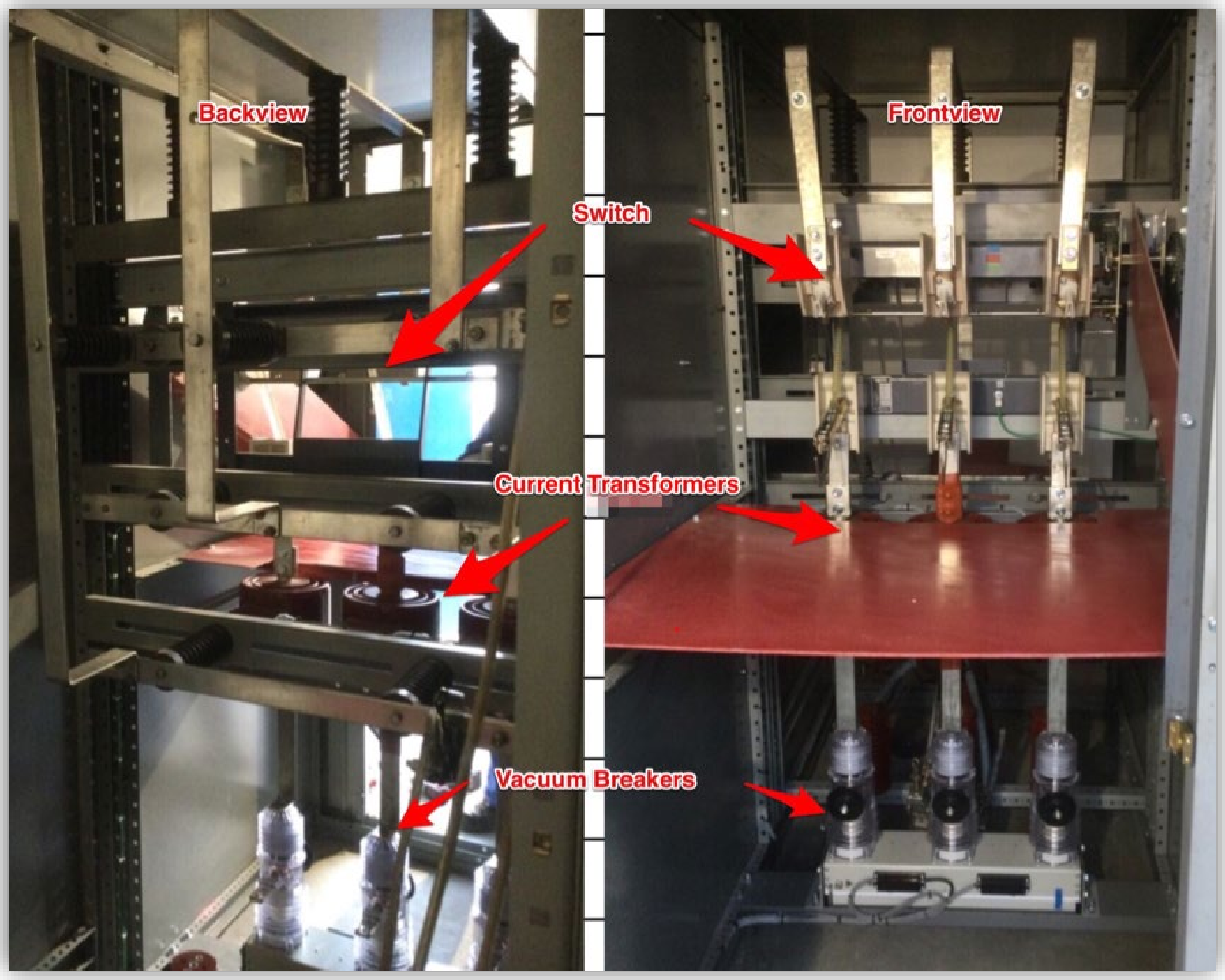


Photo 11 - Unit #6 ‘prior’ to incident with front side and backside views.

Photo 12 – Unit #6 after incident with back cover removed. Cables through floor no longer exist and are burnt off at floor level.

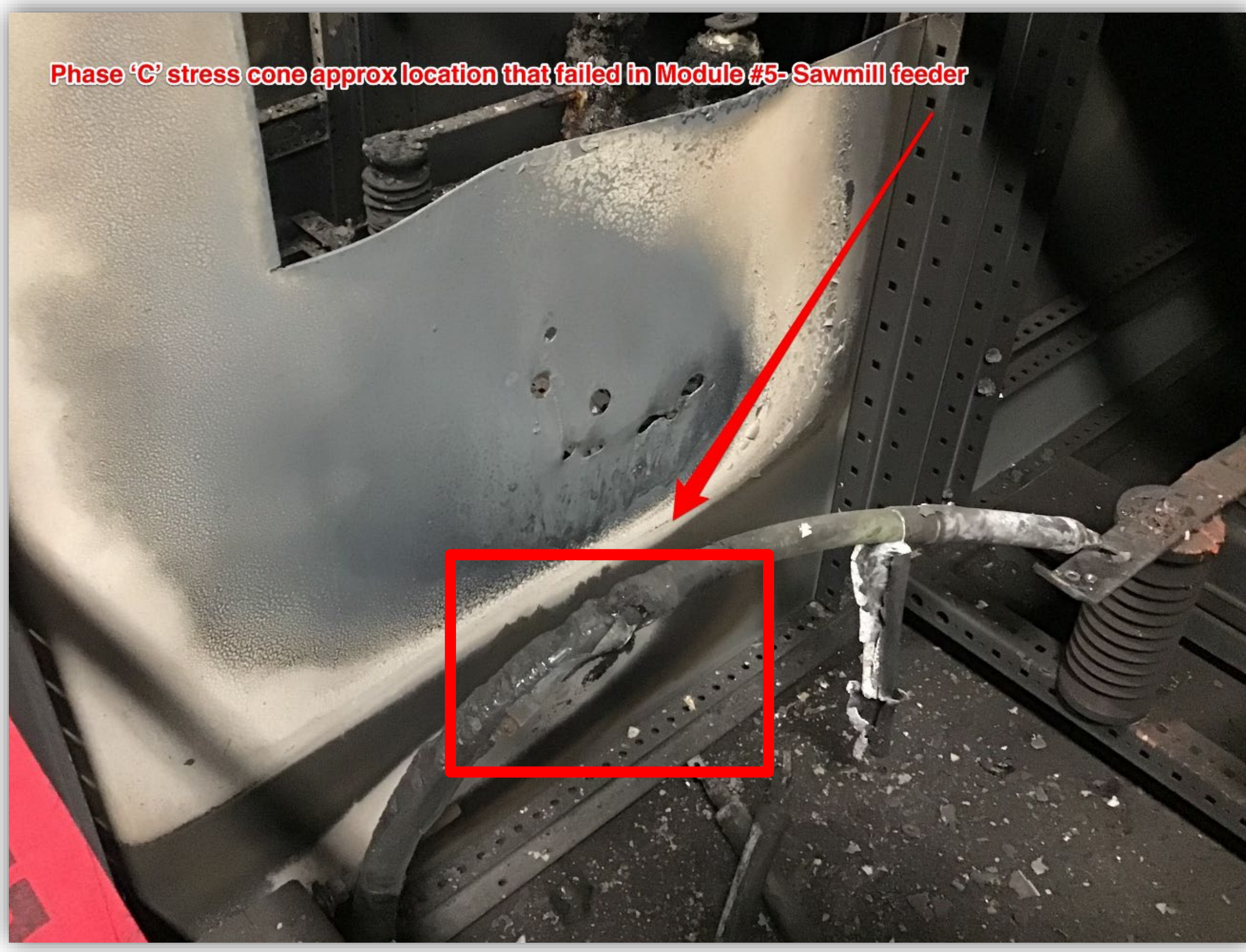


Photo 13 - Module #5 with cable laying in approximate location of operation, the cable has a noted fault on the stress cone.

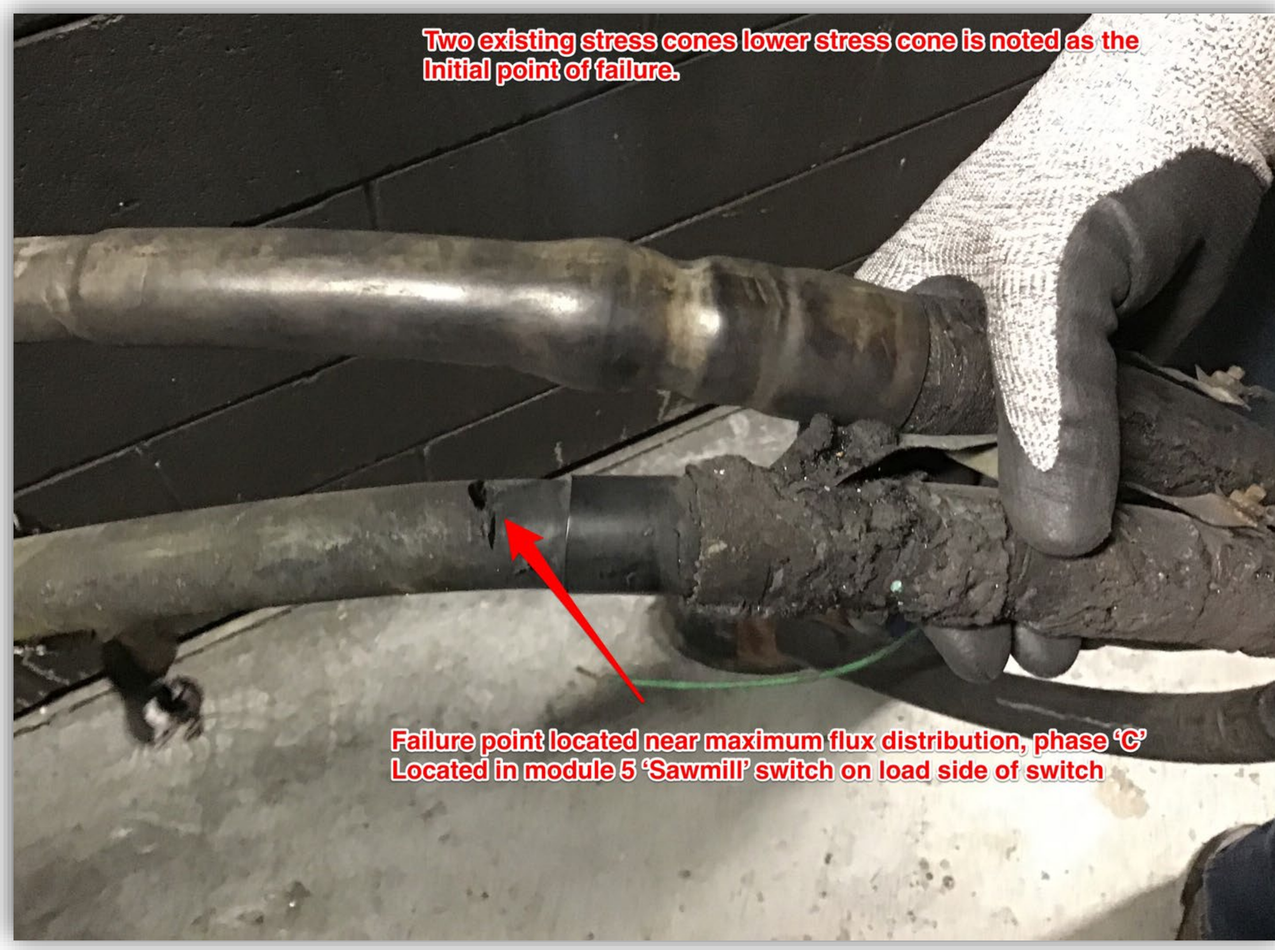


Photo 14 - Two of the stress cones cut out from Modules #5 with failed cable noting location of fault within the stress cone.

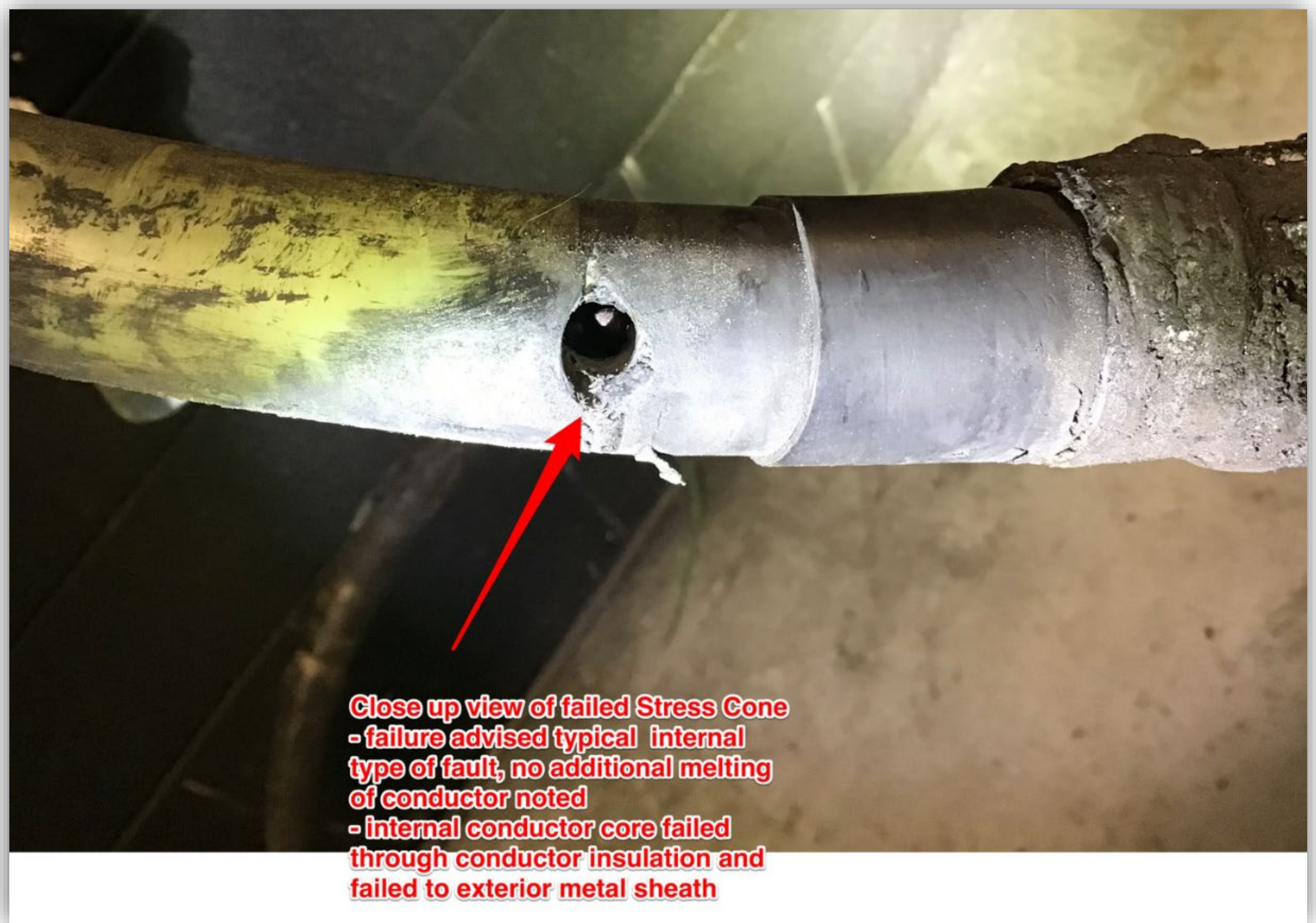
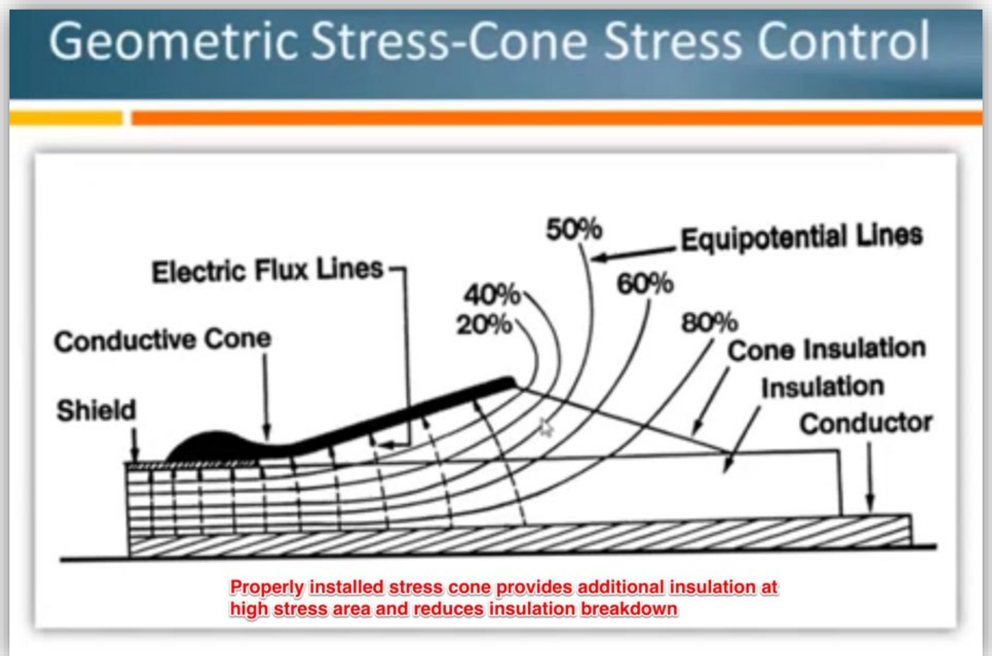


Photo 15 - Close-up photo of failure point of cable within stress cone. Interior conductor is noted to be blown out from the interior outwards.



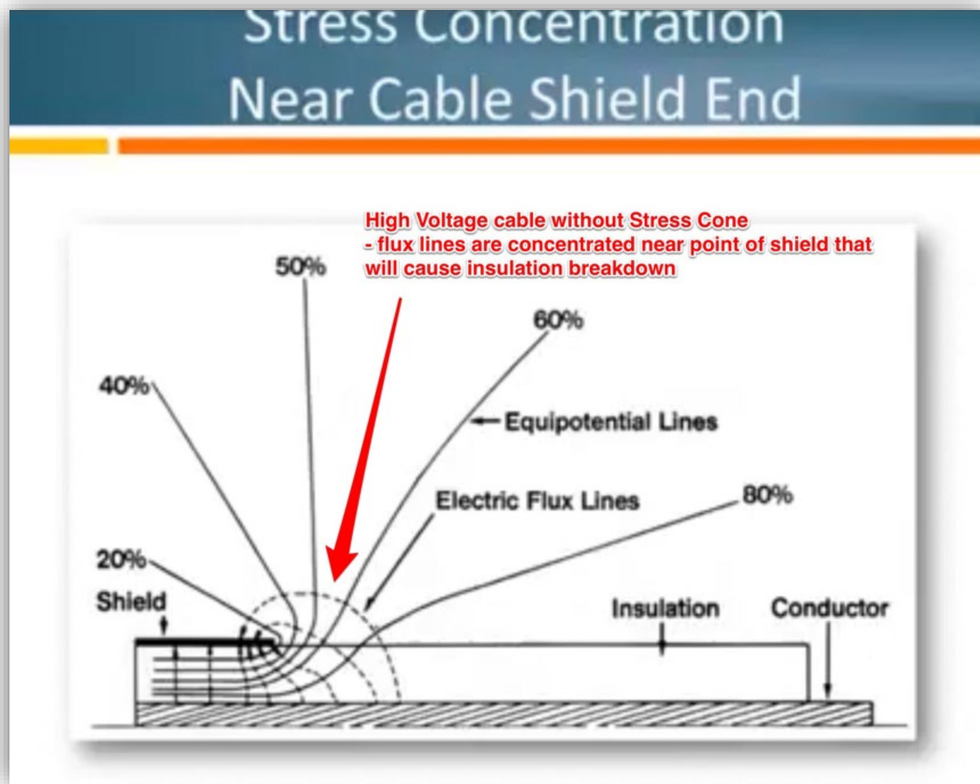


Photo 16 - Shows stress cones are installed and what they do to providing a long-lasting operation of cable terminations. Upper shows how the lines of flux are spread out to dissipate and minimize the degradation of the cable insulation. The lower diagram provides 'how' the lines of flux are contained within a short space that will cause a quick failure of the cable insulation due to heating.