Study Committee B1

Insulated Cables

11164_2022

Experiences and Insights Rehabilitating a 69kV SCFF Cable System after Pressure Loss

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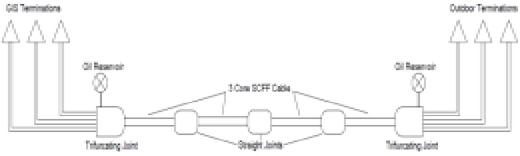
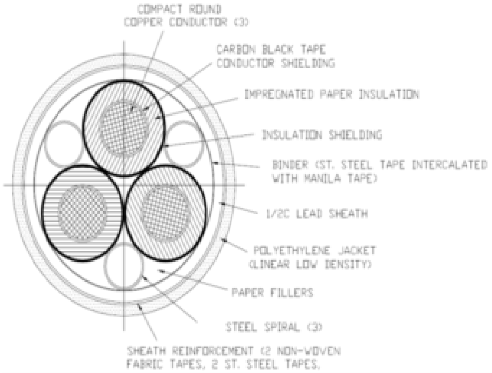
Project Overview

- A facility operator in the United States completely lost pressure on a 69kV SCFF feeder
- The circuit consisted of 700m of three core 400mm^2 cable and a reinforced 1/2C lead sheath installed in 1988
- After the loss of pressure it was unclear whether or not the cable system could be successfully rehabilitated

Single Line Schematic of Circuit



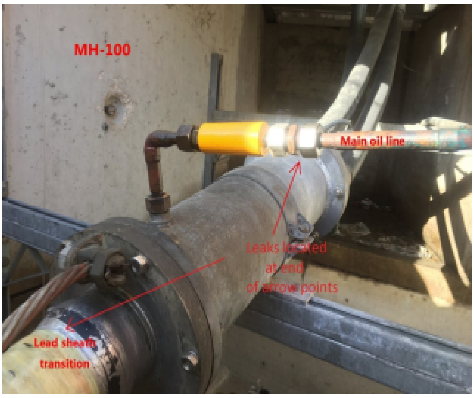
Typical 3 Core SCFF Cable



Initial Inspection

- After the cable system pressure gauge dropped to zero the facility was directed to immediately take the circuit out of service
- An inspection was then performed to determine the cause of the pressure drop and any other issues present on the cable system
- One of the trifurcating joints was leaking in two places which caused the system to lose all hydraulic pressure
- The inner valves and fittings of the oil reservoirs were severely corroded
- Initial DGA and moisture content testing showed elevated results

Leaking Trifurcating Joint



Corroded Oil Reservoirs

Leak Repair

- The old, damaged reservoirs and piping were replaced with new, pre-pressurized oil reservoirs and piping so oil could be added and the hydraulic system controlled upon repair of the leaks
- New oil reservoirs were filled with DF100 synthetic fluid
- Leaking fitting on the trifurcating joint was replaced with a new fitting
- Old, leaking lead wipe was removed and a new wipe was performed between the cable sheath and the joint body
- Lead wipe was tested for leaks using a whitewash of talc and alcohol
- Reinforcing wire was then added and sealed with self-amalgamating and PVC tapes

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continued

New Oil Reservoirs

Completed Lead Wipe with Reinforcing Wire and New Fitting

Vacuum Treatment Setup

Removal of Existing Lead Wipe and Application of New Lead Wipe

Vacuum Treating and Fluid Filling/Flushing

- The trifurcating joint as well as the outdoor terminations and piping were vacuum treated to ensure they were free of air and other contaminants
- The system was then filled with cable fluid under vacuum to restore pressure of 25 psi
- Cable fluid was flushed to get new, degassed fluid in the system
- Cable sat under pressure for 24-48 hours after flushing to allow for fluid mixing to occur

Verification Tests

- Flushing of the cable oil continued and subsequent DGA and Moisture Content testing was performed until results reached acceptable levels
- The Impregnation Coefficient test was performed to verify the hydraulic integrity of the cable system and ensure no free gas was trapped within the insulation
- Typically, a DC Hipot test would be performed to test the electrical insulation as is common practice for SCFF and HPFF cable systems
- An AC Soak Test was requested by the owner in this case, so the cable system was energized to it's rated load for a period of 24 hours under no load to ensure no faults or breakdowns were present
- The system passed the test and the feeder was returned to service

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DGA and Moisture Content Test Results

Dissolved Gas	Test Procedure (units)	Test 1	Test 2	Test 3
Hydrogen (H2)	ASTM D3612 IEC 60567 (ppm)	0.0	0.5	0.0
Oxygen (02)	ASTM D3612 IEC 60567 (ppm)	17900	<50.0	<50.0
Nitrogen (N2)	ASTM D3612 IEC 60567 (ppm)	53500	13400	11200
Methane (CH4)	ASTM D3612 IEC 60567 (ppm)	1.4	19.0	10.7
Carbon Monoxide (CO)	ASTM D3612 IEC 60567 (ppm)	8.5	20.0	8.2
Ethane (C2H6)	ASTM D3612 IEC 60567 (ppm)	6.2	57.0	21.1
Carbon Dioxide (CO2)	ASTM D3612 IEC 60567 (ppm)	462.0	118.0	22.0
Ethylene (C2H4)	ASTM D3612 IEC 60567 (ppm)	1.0	4.3	0.0
Acetylene (C2H4)	ASTM D3612 IEC 60567 (ppm)	0.0	0.0	0.8
Total Gas	(ppm)	71879	13669	11313
Test	**Test Procedure (units)**	**Test 1**	**Test 2**	**Test 3**
Water Content	ASTM D1533 IEC 60814 (ppm)	86	11	4

Table 11 from IEEE Std 1406 Section 12.1

Table 11—Guidelines for levels of gases found by DGA in SCFF cable systems (ppm by volume)

	Gas	Normal, age in years			Moderate concern	Severe concern
		< 5	5–20	> 20		
Nitrogen	N_2	50	75	100	> 300	> 500
Oxygen	O_2	25	50	70	> 100	> 300
C. dioxide	CO_2	20	50	75	> 150	> 300
C. monoxide	CO	10	20	50	> 100	> 200
Hydrogen	H_2	50	75	100	> 200	> 400
Methane	CH_4	5	15	30	> 50	> 100
Ethane	C_2H_6	10	20	40	> 75	> 150
Ethylene	C_2H_4	0	5	10	> 25	> 75
Acetylene	C_2H_2	0	0	0	> 10	> 25
	TCG	50	100	200	> 400	> 800

Impregnation Coefficient Formula and Results

$$K = \frac{\Delta V}{V}\frac{1}{\Delta P}$$

Where ΔV = Volume of oil withdrawn (l)
ΔP = Drop in pressure (bar)
V = Volume of oil in installation (l)

Oil Volume Withdrawn (ΔV)	100mL
Initial Pressure	91 kPa
Final Pressure	58 kPa
Change in Pressure (ΔP)	33 kPa
Volume of Oil in Installation	2132 L
Calculated Impregnation Coefficient (K)	**1.42x10-4 bar-1**
Maximum Allowable Impregnation Coefficient (K)	4.5x10-4 bar-1

Conclusion

- Positive pressure is essential for laminated paper cables since laminated paper is especially vulnerable to small gaps developing in the insulation during thermal cycling
- If homogenous insulation is not maintained in the cable, partial discharges are likely to occur if the cable system is energized. At this point, the system will likely be beyond repair.
- It is possible to rehabilitate a circuit that has completely lost pressure assuming there are not significant gaps that have formed and partial discharges have not occurred within the cable's insulation. Even still it must be done properly and with great care.
- It is far better and less expensive to perform routine maintenance and testing on the cable system to quickly identify and correct issues before they become a serious concern

Best Practices for SCFF Cable Systems

- SCFF cable systems are extremely reliable with some in operation for 80-90 years. SCFF cable systems will continue to operate provided they receive proper care and routine maintenance.
- Jacket tests should ideally be done once a year (at least every 5 years)
- Visual inspection performed quarterly to identify leaks, damage and corrosion
- Yearly DGA and moisture content testing on cable fluid samples
- Timely repair of jacket faults, leaks and other issues