Cigre B2 Updates from the latest Colloquium, Hakodate, Japan

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PART 1 - NEW TOOLS & TECHNOLOGIES FOR USE IN HIGH-VOLTAGE LIVE-LINE MAINTENANCE
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• REMOVE CONDUCTING TOOLS FROM BARE HAND LIVE LINE WORK
• MAKE LIVE-LINE WORK ON COMPACT STRUCTURES POSSIBLE AND EFFICIENT
• NON-CONDUCTIVE COMPOSITE MATERIALS ARE LIGHT ENOUGH TO PASS THE CART THROUGH SUSPENSION INSULATORS
COMPOSITE MATERIAL MECHANICAL BEHAVIOR

• ADHESIVE JOINTS ARE NOT REGULATED LIKE WELDED JOINTS

• PERFORM FATIGUE & ACCELERATED AGEING TESTING: DESIGN LOAD OF 335 LBS (1500N)
COMPOSITE MATERIAL MECHANICAL BEHAVIOR

- UPON SELECTION OF MATERIAL AND ADHESIVE, A FINITE ELEMENT MODEL OF THE CART IS CREATED
- BOTH SYMMETRIC AND ASYMMETRIC LOADING WERE APPLIED TO THE CART
ELECTRICAL FIELD TEST

- ELECTRICAL FIELD & ELECTRICAL POTENTIAL DISTRIBUTION
- AT 400 kV, MAX ELECTRIC FIELD OF 16.8 kV/ft (55 kV/m)
CART TESTED AT A 400 kV LIVE LINE TRAINING FACILITY AND THEN ON AN ENERGIZED 400 kV LINE AS SHOWN BELOW
COMPOSITE CHAIR FOR CHANGING INSULATORS

- ACCESS ENERGIZED PHASES FROM EITHER THE GROUND OR THE TOWER LEG
- SUBJECTED TO DESTRUCTIVE & NON-DESTRUCTIVE TESTING TO DETERMINE SAFETY FACTORS ASSOCIATED WITH VARIOUS LOAD CONDITIONS
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PART 2 - CORROSION EVALUATION OF ACSR CONDUCTOR, TEPCO POWER GRID, JAPAN

- CORROSION OCCURS ON ACSR LINES EXPOSED TO DELETERIOUS ATMOSPHERIC CONDITIONS DUE TO SEA SALT PARTICLES AND/OR ACID FOG

- USE OF ATMOSPHERIC CORROSION MONITORS (ACM) TO DETERMINE THE NATURE OF CORROSION AND A QUANTITATIVE EVALUATION OF THE CORROSIVITY IN A SHORTER PERIOD THAN STANDARD EXPOSURE TESTS
  - SEASIDE AREAS:
    - PITTING OF ALUMINUM OUTER LAYER DUE TO AIRBORNE SALT. DEGRADATION OCCURS BETWEEN ALUMINUM AND STEEL STRANDS DUE TO GALVANIC CORROSION
  - ACID FOG (INDUSTRIAL POLLUTANTS):
    - STEEL CORE CORRODES WITH LITTLE EVIDENCE OF CORROSION IN OUTER ALUMINUM STRANDS
ACM FOR STEEL, ZINC, AND ALUMINUM
OUTPUT CURRENT (PROPORTIONAL TO CORROSIVITY) VS RELATIVE HUMIDITY

(a) Kamisu region (Nov 01, 2003 to Dec 04, 2003)

(b) Nikko region (Nov 02, 2001 to Dec 04, 2001)
CORRISION MECHANISMS FOR SEA SALT (LEFT) & ACID FOG (RIGHT)

(1) Sea salt particles are present in the atmosphere

(2) Sea salt particles adhere to the line surface due to wind

(1) Suspended substances and gases are present in the atmosphere

(2) Water film forms on the line due to fog

- Aluminum wire
- Steel core wire (galvanized steel wire)
- Sea salt particles (NaCl)
- Corrosion product
- Moisture/electrolyte solution
- Snow-melting salt (NaCl)
- Sulfurous acid gas (SO₂)
- Electrolyte solution

Salt seeps inside the line

Suspended substances and gases dissolve in the water film and seep inside the line by capillary action
CORROSION MECHANISMS FOR SEA SALT (LEFT) & ACID FOG (RIGHT) — CONTINUED

(3) Occurrence of pitting and galvanic corrosion

- Occurrence of galvanic corrosion between galvanized steel core wire and inner layer aluminum wire
- Oxide film on outer layer aluminum wire surface is broken → Occurrence of pitting

(4) Accumulation of aluminum corrosion products

- Inner layer aluminum wire becomes corroded by galvanic corrosion → Accumulation of aluminum corrosion products

(3) \( \text{SO}_4^{2-} \) diffuses inside the steel core

- \( \text{SO}_4^{2-} \) works to suppress general corrosion in aluminum, and forms a stable oxide film. \( \text{SO}_4^{2-} \) permeates into the steel core.

(4) Steel core corrosion caused by \( \text{SO}_4^{2-} \)

- Generation of red rust
- \( \text{SO}_4^{2-} \) corrodes the zinc in galvanized steel wire, then corrodes the steel once the zinc plating is gone.
- Reduction in thickness of zinc plating
DIFFERENCES IN ACSR CORROSION

(a) Seaside area

(b) Acid fog area
EDDY CURRENT FLAW DETECTION

Measurement of cross section on Line N (TACSR810mm²)

Remaining cross section (%)

Distance from No. 1

Point exposed to smoke
CONCLUSIONS WITH ACM TECHNOLOGY

• WITH ACM’S IT IS POSSIBLE TO IDENTIFY THE CORROSITIVITY OF THE ATMOSPHERIC ENVIRONMENT ON THE ALUMINUM, ZINC, AND STEEL COMPONENTS OF AN ACSR CONDUCTOR

• THE ACM’S ALLOW A QUANTITATIVE DESCRIPTION OF THE ATMOSPHERIC CORROSION POTENTIAL BASED ON SEASIDE OR ACID FOG LOCATIONS

• BY INSTALLING THE THREE TYPES OF ACM AND PERFORMING A RELATIVE COMPARISON OF THE OUTPUT CURRENT, THE DOMINATING CHARACTERISTIC OF THE ENVIRONMENT (NaCl or SOx) CAN BE QUANTIFIED. WHEN GOVERNED BY SOx, EDDY CURRENT FAULT DETECTION CAN BE USED TO EVALUATE THE CORROSION OF THE STEEL

• THESE TECHNIQUES OFFER TSO’S EFFICIENT METHODS TO MONITOR THE HEALTH OF TRANSMISSION LINES IN HARSH ENVIRONMENTS. ADDITIONALLY, IN KNOWN AREAS OF CONCERN, THE EXTENT OF CORROSION AND ASSOCIATED LOSS OF STRENGTH CAN BE EFFICIENTLY QUANTIFIED AND MAINTENANCE SCHEDULES CAN BE IMPLEMENTED AS DEEMED NECESSARY
PART 3 - ENGINEERING & PERFORMANCE OF LC SPIRAL RODS ON CONDUCTORS AT ROAD CROSSINGS
HYDRO-QUEBEC, CA

THEY GET A FAIR AMOUNT OF ICE IN THE GREAT WHITE NORTH...
CURRENT DE-ICER SYSTEM AT LEVIS SUB IS DESIGNED TO BE OPERATED AS AN HVDC RECTIFIER CAPABLE OF PROVIDING 7200 AMPS OF DC CURRENT TO MELT ICE ON (4) 735 kV LINES AND (1) 315kV DOUBLE CIRCUIT LINE FOR A TOTAL CIRCUIT LENGTH OF APPROXIMATELY 350 MILES

**Figure 1:** Length of the lines de-iced from the Levis sub-station
In Quebec City, many of these transmission lines cross highways and busy roads. Operating the De-Icer greatly increases the risk of ice falling on busy roadways. Closing the roads during operation is not an option for logistical reasons.
LOW CURIE (LC) FERROMAGNETIC MATERIAL

- Most effective method to melt ice on small segments of OHTL is to avoid methods involving external power supply.
- Wrapping the conductor in a magnetic material enables heat generation through hysteresis and eddy current losses, but this will overheat the conductor in summer conditions.
- A Low Curie ferromagnetic material has the unique characteristic of losing its magnetic properties above a certain temperature. Thus, the conductors are not heated in warm weather.

A Fe-Ni LC material with a Curie temp of around 0° was selected. It has the desirable property of large heat generation in a small magnetic field (low current) and low heat generation in a high magnetic field (large current).

![Graph](image)

Fig. 1. – Curie temperature $T_c$ (°C) vs. Ni content (% atomic) for Ni-Fe alloys: ■ present Mössbauer experiment results, △ CRANGLE et al. (2), ▲ WEISS (3), ▽ YURCHIKOV et al. (4), ○ ASANO (7).
FIELD INSTALLATION

Winding Machine (WM); Bobbin of LC wire; Field training for crews
FOUR TRAINED TEAMS WORK ON TWO PHASES AT A TIME
IN FEBRUARY, 2018, QUEBEC CITY WAS HIT WITH FREEZING RAIN AND ICE. ALL ROAD CROSSINGS WITH LC RODS INSTALLED PERFORMED AS ANTICIPATED AS SHOWN HERE.
PART 4 - MODELING AND QUANTIFYING THE AERODYNAMIC CHARACTERISTICS OF TRANSMISSION LINE STRUCTURES TO AVOID AND MITIGATE AEOLIAN-INDUCED VIBRATIONS

- Tall slender transmission structures are often subjected to wind conditions that lead to complex Vortex Induced Vibrations (VIV).
- The investigation and study work described herein started with such a phenomenon that lead to a failure

- 345 kV lightning masts
- 75’ tubular steel hexagonal shaft with
- 10’ Sch. 30 pipe ‘spike’ bolted on top.
- Flat terrain – steady winds. Short time to failure
Transmission structures represent a bluff structure. A bluff structure is one in which the flow separates from large sections of the structure’s surface. Davit arms and, in some cases, poles (static mast for example) are very long slender structures that are prone to vortex shedding.

When the vortex shedding frequency approaches the structure’s natural frequency, the structure can undergo near resonant vibration (large amplitude).

The critical wind speed for this type of vibration is given by the following formula:

\[ V_i = \frac{\eta_i \times D}{S} \]

- \( \eta_i \) = ith Natural Frequency of Structure
- \( S \) = Strouhl’s Number \( \sim .2 \)
- \( D \) = Drag Diameter

The problem is that the Strouhls Number is a subjective quantity based on the Reynold’s Number.
COMPUTATIONAL FLUID DYNAMICS (CFD) ANALYSIS AS A PRECURSOR TO FEA

- Cloud based software on a browser
- Client is charged for computer time
- CFD simulation analyses take approximately (7) seven days to complete running on several processor units (cores)
- Start with a 3D Solid CAD model (STEP or IGES model export)
The model and Domain are ‘meshed’

- Boundary Conditions
  - Wind speed at bounding surfaces of the domain are set to 0 mph.
  - Initial uniform wind is the Initial Condition on this surface
- Scaling and the Laws of Similitude will not work: loss in numerical accuracy
• ATTEMPT TO SUBSTANTIALLY DISRUPT THE AIRFLOW USING AN ECONOMIC STRAKE LAYOUT THAT COULD BE IMPLEMENTED WITHOUT TAKING OUTAGES. THESE COULD BE INSTALLED WITH RELATIVELY SMALL EQUIPMENT.

• NOTE; VERY FINE REFINEMENTS TO CAPTURE THE ANGLES WELDED TO THE SHAFT WALL LEADS TO 8.52 MILLION 3D ELEMENTS/CORELS. SIGNIFICANTLY INCREASING COMPUTATIONAL TIME.
S1 & S2 Models at a Wind Excitation Speed of 22 MPH

- Symmetry in Stress Amplitude
- Frequency ~ 3.5 Hz

Time to generate vortex shedding ~ 8 seconds
S1 & S2 MODELS AT A WIND EXCITATION SPEED OF 44 MPH

Note: approximately 2 seconds to initiate VIV

FREQUENCY ~ 6.5 Hz

Symmetry in Amplitude

No symmetry in Amplitude
Shortly before publication, significant advancements have been made in the commercially available software. As a sample, the simulation below of the original static mast was modeled with helical strakes. The airflow at all speeds indicates what we assume: the helical strakes are effective. The significant aspect: this analysis, on new processors, took two hours rather than seven days, and the process of creating the mesh has been simplified.
• New software developments and modeling techniques allow more complicated shapes such as substation dead-end towers and possibly lattice towers.
CONCLUSIONS

• There is good correlation between the CFD/FE analysis in comparison to the older FE analysis, but the latter required field testing to verify structure damping/resonant frequency behavior as well as estimates of the Strouhl Number.

• Advances in software and processors now allow our industry to predict and design for aeroelastic behavior.

• More laboratory testing of structures with small mass ratios needs to be conducted (similar to the 1979 IEEE study).

• Wind tunnel testing to corroborate these CFD simulations needs to occur as well; Unfortunately, wind tunnel testing is typically not economical.
  – Experimentally determine the Reynolds number (and hence the Strouhl) number for low mass ratio structures
  – Determine the best approach to avoiding VIV: either structures stiff enough that they are not susceptible or the installation of strakes or other airflow-interrupters.