Overhead Transmission Lines Monitoring

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Overhead Transmission Grid Monitoring

Today’s Operation Challenges for Overhead Transmission Grid:

- Sag/Clearance Monitoring
- Conductor Overheating
- Renewable Energy Integration
- Resiliency - Faster restoration of power after outage
- Reduce Impact of Scheduled Maintenance
- Maximize Asset utilization
- Enhance Asset Reliability
- Galloping Prevention
- Ice Detection

- Industry experience from around the globe for solution implementations by
Overhead Transmission Line Rating in Today’s Operation

**Static Rating** - is determined based on highly conservative set of static environmental conditions, and doesn’t represent the true maximum capacity of the transmission line, which varies over time depending on the environmental conditions.

**Dynamic Line Rating** - is defined as the maximum current that can be transferred through a transmission line, without the “conductor temperature” exceeding its maximum limit, and thereby maintaining the “maximum sag (minimum clearance)” of the conductor below its limits.

- Weather conditions – eg: wind speed, air temperature, sunlight, etc
- Location – latitude, elevation, line direction
- Current through the conductor
- Conductor characteristics

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Example: Drake Conductor 795 AWG 26/7

- Air temperature **40°C**
- Wind speed is **0.5 m/s** perpendicular to conductor
- Emissivity & absorptivity is **0.5** each
- Elevation – sea level
- Clear sky, 12pm July 4

Max current @ Max conductor temperature without sagging beyond its limits

903A @ 90°C - Thermal Rating

- **↓ 10°C to 30°C**: +10% to 999A
- **↑ to 1.5 m/s**: +35% to 1250A
- **↑ to 5 m/s**: +90% to 1715A

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Solution for Real-time Ampacity Monitoring

- Parameters influencing line capacity:
  - Ambient temperature – “reasonably predictable”, bases for Seasonal Ratings (SR), and Ambient Adjusted Ratings (AAR)
  - Solar radiation
  - Wind – most influential and least predictable

\[ I^2R(T_c) + p_s - p_c - p_r = \rho C_p \frac{\Delta T_c}{\Delta t} \]
Which Weather variable influences T-Line Capacity the Most?

T-Line Capacity vs. Solar Radiation

T-Line Capacity vs. Ambient Temperature

T-Line Capacity vs. Wind Speed

T-Line Capacity vs. Wind Angle

Ampacimon
Smart solutions for a dynamic grid

Focus Zone
• Founded 2009 as Spin-off of University of Liege (ULg), Belgium
  ✓ Research started 2003
  ✓ Exclusive, patented methods (4 awarded/pending patents)
  ✓ Partner to the USA WATT Coalition
  ✓ Partner to European Project Twenties
  ✓ Steady, profitable growth since 2010 (Top 50 fastest growing SMEs 2016 (#29) and 2017 (#13) per Deloitte)
  ✓ Key utility customers in the US, Europe, and Asia.
  ✓ Global distribution partners network in 15+ countries
  ✓ Ampacimon has installed almost 340 sensors in over 70 lines so far worldwide
  ✓ North American Ampacimon Inc. since 2017
  ✓ Focused on Transmission and Distribution grid operators
  ✓ Supplier of grid monitoring solutions
  ✓ External partnerships with many global players, like:

“Smart Solutions for a dynamic grid”
State-of-Art Technology for Real-time Ampacity Monitoring

**Sag Measurement**
The fundamental frequency forms the exact signature of the span’s sag measurement.

**Mean conductor temperature**
Accurate State Change Equation

**Transmission Line Performance**
- Real time Sag monitoring
- Real time mean conductor temperature monitoring
- Real-time Dynamic Line Rating
- Intra-day Transmission Capacity Forecast
- Day-ahead Transmission Capacity Forecast
- Ice Detection
- Galloping Detection

**Wind Speed measurements**
(Effective perpendicular component)
(from 0.3 m/s)
- >2m/s w/ Swing Angle
- <2m/s w/ Aeolian Vibrations

**Other Weather Variables**
- Ambient temperature
- Solar radiation

**Line Information**
- Line Current
- Conductor parameters

**Line Tension**
- w/ Tension Monitor within Sensor (for ice detection)

- 3D Accelerations, measured with accelerometers with sensitivity > 100µG
- T-Line Vibration Frequency Spectrum (up to 100 Hz; up to 12.5 Hz used for Sag & Wind speed measurements

- **00:19:08**

- **Real time Sag monitoring**
- **Real time mean conductor temperature monitoring**
- **Real-time Dynamic Line Rating**
- **Intra-day Transmission Capacity Forecast**
- **Day-ahead Transmission Capacity Forecast**
- **Ice Detection**
- **Galloping Detection**
Sag from fundamental frequency:

- Levelled span

\[ S \overset{(a.1)}{=} \frac{wL^2}{8H} = \frac{\rho g L^2}{8H} = \frac{g L^2}{8} \frac{1}{H/\rho} \]

\[ \overset{(a.3)}{=} \frac{g L^2}{8} \frac{1}{4L^2 f_0^2} = \frac{g}{32f_0^2} \]

- Inclined span

\[ S \overset{(b.1)}{=} \frac{w(L^*)^2}{8H^*} = \frac{\rho g (L^*)^2}{8H^*} = \frac{g (L^*)^2}{8} \frac{1}{H^*/\rho} \]

\[ \overset{(b.3)}{=} \frac{g (L^*)^2}{8} \frac{1}{4(L^*)^2 f_0^2} = \frac{g}{32f_0^2} \]

To measure sag; do not need any external data or conditions such as span geometry, weight of cable, load, weather, topology, suspension movement or creeping.

\[ f_0 = \frac{1}{2L} \sqrt{\frac{T}{m}} \]

\[ \text{sag} = \frac{g}{32f_0^2} \]
Ampacimon Patented effective wind measurements:

- **Wind Speeds > 2m/s**
  - Swing Angle Methodology

- **Wind Speeds < 2m/s**
  - Aeolian Vibrations and Strouhal Equation Methodology

Equation:

\[
\text{LIFT COMPONENT} + \text{DRAG COMPONENT} = \text{Expected Wind Speed}
\]
State-Change Equation to Measure Conductor Temperature

3.4 Formulas IEEE 738 Standard

3.4.1 Steady-state heat balance

\[ q_e + q_i = q_s + \alpha^2 R(T_c) \]

\[ I = \frac{q_e + q_i - q_s}{R(T_c)} \]

\[ q_s = 0.0178 A T_{a0} \left( \frac{T_c + 273}{100} \right)^4 - \left( \frac{T_c + 273}{100} \right)^4 \]

3.4.2 Non-steady-state heat balance

\[ q_e + q_i + m C_p \frac{dT_e}{dt} = q_s + \alpha^2 R(T_c) \]

\[ \frac{dT_e}{dt} = \frac{1}{m C_p} \left[ a q_s + q_e - q_i - q_s \right] \]

3.4.3 Forced convection heat loss rate

\[ q_d = 1.01 + 0.0372 \left( \frac{D_p V_{e} \mu_i}{\mu} \right)^{0.52} k_i K_{fgh}(T_e - T_d) \]

\[ q_c = 0.0119 \left( \frac{D_p V_{e} \mu_i}{\mu} \right)^{0.6} k_i K_{fgh}(T_e - T_i) \]

NOTE—The English unit equivalents of these equations can be found in A.2.1.
Dynamic line rating & Capacity forecasting applications

- Increase efficiency of exiting T-infrastructure, Optimize CAPEX by Deferring or Avoiding New T-infrastructure:
  
  Increase capacity with DLR on existing transmission lines, defer new T-line builds.

- Monitor Safety & reliability metrics on Aging T-infrastructure: Monitoring sag/clearance plus using real capacity on old T-infrastructure with DLR (which 50% of time, extra 20% capacity) vs. reconductoring or rebuilding old T-lines. *Lines with NERC alert monitoring are great candidates.

- Reduce impact of Scheduled Maintenance: Reduce the need to redispatch generation and re-route power flow during Maintenance Outages, by installing DLR on neighboring T-lines or corridors.

- Faster restoration after severe weather events (Resiliency): increasing resiliency of the grid by faster restoration of power after severe weather events, by utilizing DLR to increase capacity of energized lines, while restoring downed lines.

- Renewable Energy like wind or solar Integrations

- Galloping Detection

- Ice Detection
Ampacimon Deployed its solution on 60+ Transmission Lines (including system-wide full-scale deployments)

Across all Transmission voltage levels:
- 63 kV
- 70 kV
- 90 kV
- 138 kV
- 150 kV
- 161 kV
- 220 kV
- 275 kV
- 380 kV
- 400 kV
- 735 kV

Maharashtra State Electricity Transmission Co. Ltd.
Critical Span 75% of time

Perpendicular Wind Speed on Most Critical Span

Effective Perpendicular Wind Speed Measured by Ampacimon Sensors

Ground profile across Most Critical Span

Most Span shielded from wind due to the elevation profile perpendicular to the span

T-line orientation

N

S
Key Wind Metrics near XYZ Line:

• High wind blows from either **North or South**.
• Mean Wind speed for this line: **4.4m/s**
• Only less than 4.5% of time wind speed was below **1m/s**
• Peak direction was from south side, **9.6% of time**.

**Inference of Wind Speed impact on XYZ Line**

• Wind speed in the direction perpendicular to the T-line is the most influential factor for dynamic line rating.
• Weather station statistics indicate that XYZ Line is located in a area of good wind potential.
• However, the line has moderate DLR capacity (over static rating) as most of the wind is in the direction of north or south which is the parallel to the orientation of XYZ line, and not perpendicular.
Increasing Tie-Line Import Capacity

Challenge

- Belgium Peak Load: 13 GW
- Summer 2014: Loss 3x Nuclear Power Plants of 1GW each
- Belgium required to import power from France & Netherlands, however, maximum import capacity was insufficient during specific winter weather events

Solution

- Agreement to increase cross-border transit
- 8 lines (380kV) equipped in 2 months with Real-time Ampacity is monitored with Day-ahead forecast with Gains up to 40% in Real-time (1200 MW)
- D-2 forecast allows to increase total import capacity by extra 450MW)
220 kV T-Line Scheduled Maintenance

Challenge
• Scheduled outage on a 220kV line
• Required significant redispatch and rerouting of power flows involving additional costs

Solution
• Adjacent line equipped with 4 devices ADR SENSE
• Ampacity is monitored with ADR OPERATE
• This line carries the extra load for 3 months, average +40% capacity

Key take away
• Increases system availability and reliability during long scheduled outages
• System can be re-deployed on other lines
Dynamic Line Rating for Scheduled Maintenance Application: Two Parallel 380 kV Lines (1 & 2b)

Ampacimon DLR deployed on both lines. 380kV, 53Km, 8x Ampacimon ADR Sensors on each line, Re-deployable

Scheduled Maintenance Outage of Line 2b, till Oct 2017

Scheduled Maintenance Outage of Line 1, after Apr 2018, upgrading to HTLS Conductor, will redeploy sensors on other lines
150kV Radial T-Line Overload during winter

Challenge
• Ski resort area fed by 150kV radial line sees load increase during winter over the years
• Significant Investment would be required to upgrade transmission line in mountainous areas
• Public safety issue

Solution
• In 3 months, Critical spans monitored with ADR SENSE
• Ampacity/Sag is monitored with ADR OPERATE
• In winter, up to 40% gain above nominal rating
• Sufficient to cope with this seasonal variability

Representation of Weather Conditions

Effective Wind Speed on Most Critical Span

Period: from 2018-03-21T00:00:00.000Z to 2018-05-16T00:00:00.000Z

90% of the time DLR is >140%
95% of the time DLR is > 137%
98% of the time DLR is > 133%

Effective Wind Speed Measured by Ampacimon Sensors

(cumulative, annual)

Period: from 2018-05-01T00:00:00.000Z to 2018-05-15T00:00:00.000Z

Wind Speed and Direction from near-by Weather Station

Critical Spans w/ Ampacimon Sensors

(cumulative, annual)

Period: from 2018-03-21T00:00:00.000Z to 2018-05-16T00:00:00.000Z

90% of the time DLR is >140%
95% of the time DLR is > 137%
98% of the time DLR is > 133%

Wind Speed and Direction from near-by Weather Station
Dynamic Line Rating (real-time)

- 90% of the time the line capacity (w/ DLR) is greater than 129% of static rating
- 95% of the time the line capacity (w/ DLR) is greater than 124% of static rating
- 98% of the time the line capacity (w/ DLR) is greater than 120% of static rating

Critical Spans w/ Ampacimon Sensors

T10-T11 is the most critical span
69% of time
Dynamic Line Rating (real-time)

- Average (1 year) of +26% additional transmission capacity over seasonal static rating
- +25% capacity over 50% of time in 1 year
- +6% capacity over 90% of the time in 1 year
- Less than 6% of time the dynamic line rating is below the seasonal static rating – risk in using static rating during this time, which occurs in Apr/May & Sep/Oct when the change in seasonal static rating is implemented.

Effective Wind Speed Measured by Ampacimon Sensors (cumulative, annual)

Period: from 2017-02-01T00:00:00Z to 2018-02-02T00:00:00Z

Wind Speed & Direction from nearby Weather Station

Critical Spans

Wind direction:
- N
- T-line orientation
- S