SMARTLINE®

Transmission Line Rating Platform



Unique Advantages

Numbers to know:

<1%

A complete SMARTLINE implementation is typically less than 1% the cost of reconductoring the line.[1]

3 Months

Typical time for a SMARTLINE implementation from decision to full operation.

10-25%

The additional power transfer capacity made available 95% of the time.[2]

[1]J. C. McCall and T. Goodwin, "Dynamic Line Rating as a Means to Enhance Transmission Grid Resilience," in *2015 CIGRE Grid of the Future Symposium*, Chicago, IL, 2015.

[2]Oncor Electric Delivery Company, "Final Report Dynamic Line Rating - Technical Performance Report," Oncor, 2013.

TABLE OF CONTENTS

The SMARTLINE® Platform	4
TLM® Conductor Monitor	6
SMARTLINE-DLR™ Software	8
SMARTLINE-TCF™ Software	9
SMARTLINE Process	10
Conductor Asset Monitoring	12
Data Security & Interfaces	14

LINDSEY SYSTEMS

SMARTLINE® Transmission Line Rating Platform

The SMARTLINE platform consists of cloud-based software and line mounted sensors which work together to develop real-time dynamic line ratings and highly accurate forecasts of transmission line power carrying capacity. The system ensures ratings and capacity forecasts are in compliance with electrical clearance limits and avoid conductor thermal overloads. Forecasts can be provided in one-hour to one-week increments with 98% or better confidence. SMARTLINE is ideal for engineering, operations, and planning functions. The system can be easily integrated with EMS systems in both day-ahead and real-time markets.

SMARTLINE SYSTEM OVERVIEW

MEASURE • RATE • FORECAST • MONITOR

The SMARTLINE Platform provides real time line ratings, forecast line capacity, and meaningful measurements of conductor behavior.

Four elements of the SMARTLINE System provide seamless line monitoring, DLR and transmission capacity forecasting solutions.

COMPONENTS OF THE SMARTLINE SYSTEM:

- MEASURE: Lindsey **TLM® Transmission Line Monitors** provide the real-time conductor behavior information required by the SMARTLINE software systems.
- RATE: The **SMARTLINE-DLR™ Software** engine uses active learning techniques to develop a conductor behavior model that provides real-time dynamic line ratings (DLR) for each monitored transmission line.
- FORECAST: The **SMARTLINE-TCF™ Software** engine develops forecast line ratings for use in emergency situations, day-ahead markets, and other short- to medium-horizon operations.
- MONITOR: The optional conductor asset monitoring module for SMARTLINE provides real-time indication of conductor life by tracking loss of strength.



Transmission line congestion associated with renewable energy can often be relieved or eliminated through the application of DLR.

SMARTLINE® TCF Dashboard

SMARTLINE provides both detailed graphical information showing line information, forecasts, and weather parameters, and simple numeric only ratings for use on EMS screens. Any data may also be imported directly to EMS with ease. All data collected by the conductor monitors and real-time or forecasted weather data may be viewed graphically or exported for off-line analysis.

Configurable Alarms: The SMARTLINE system provides configurable alarms. Both comparative and limit based alarms for TLM data and/or SMARTLINE calculated ratings may be set. Limit based alarms are tied to one or more specified limits for any metric. Comparative alarms are based on a comparison to previous data or other related metrics. SMARTLINE also provides means to reduce or eliminate redundant alarms.

Perpendicular Wind Speed: Perpendicular wind speed is particularly important in computing DLR. The effective perpendicular wind speed across the length of the conductor span is developed in SMARTLINE-TCF by means of CIGRE TB498-2012 methodology using the directly measured values from each TLM and live weather data. The effective perpendicular wind speed is available for display on the SMARTLINE dashboard.

EMS Operator Screen:

Numeric display of critical data



Detailed Forecast Display:

RATE:

SMARTLINE-DLR™

The shape of this curve is representative of the rapidly fluctuating nature of dynamic line ratings.

FORECAST:

SMARTLINE-TCF™

Patented algorithms indicate the line may be operated at the forecast level with a 98% confidence factor. Two-hour (orange) and 24-hour (green) forecasts as indicated.

Utility Provided:

2-Hour Emergency (red) and Static Line (gold) ratings provide a familiar frame of reference. Users can specify this type of custom information to be added during system set-up.



MEASURE:

Data from TLM® Monitor

Display of the actual power being carried by the line. Other displays (not shown) show additional metrics.

TLM® Transmission Line Conductor Monitor: MEASURE

SMARTLINE® requires real-time information regarding conductor behavior. The TLM conductor monitor is an accurate, real-time, conductor clearance measurement device for use with the SMARTLINE system. The Lindsey TLM Conductor Monitor provides a complete picture of conductor behavior including actual conductor clearance-to-ground, conductor temperature, and line current. Unlike other transmission line monitors that use other measurements to infer sag, the TLM monitor provides accurate, actionable, clearance-to-ground distance measurements. The TLM monitor is an easily installed, self-powered conductor monitoring solution for system voltages up to 765kV.

Conductor Clearance

The distance to ground from the conductor is measured using an on-board LIDAR sensor providing a highly accurate line clearance measurement regardless of tower or insulator motion, varying span lengths or other line conditions. Multiple TLM monitors can also be used to ensure line clearance is maintained to under-crossing lines.

Conductor Sag

The expansion and contraction of a conductor based on thermal and mechanical loads results in a change in the sag of the conductor across its span. The TLM contains an inclination sensor which provides direct measurement of the conductor's inclination as it relates to sag. This measurement is included as part of SMARTLINE's DLR and Asset Monitoring learned behavior models.

Line Current

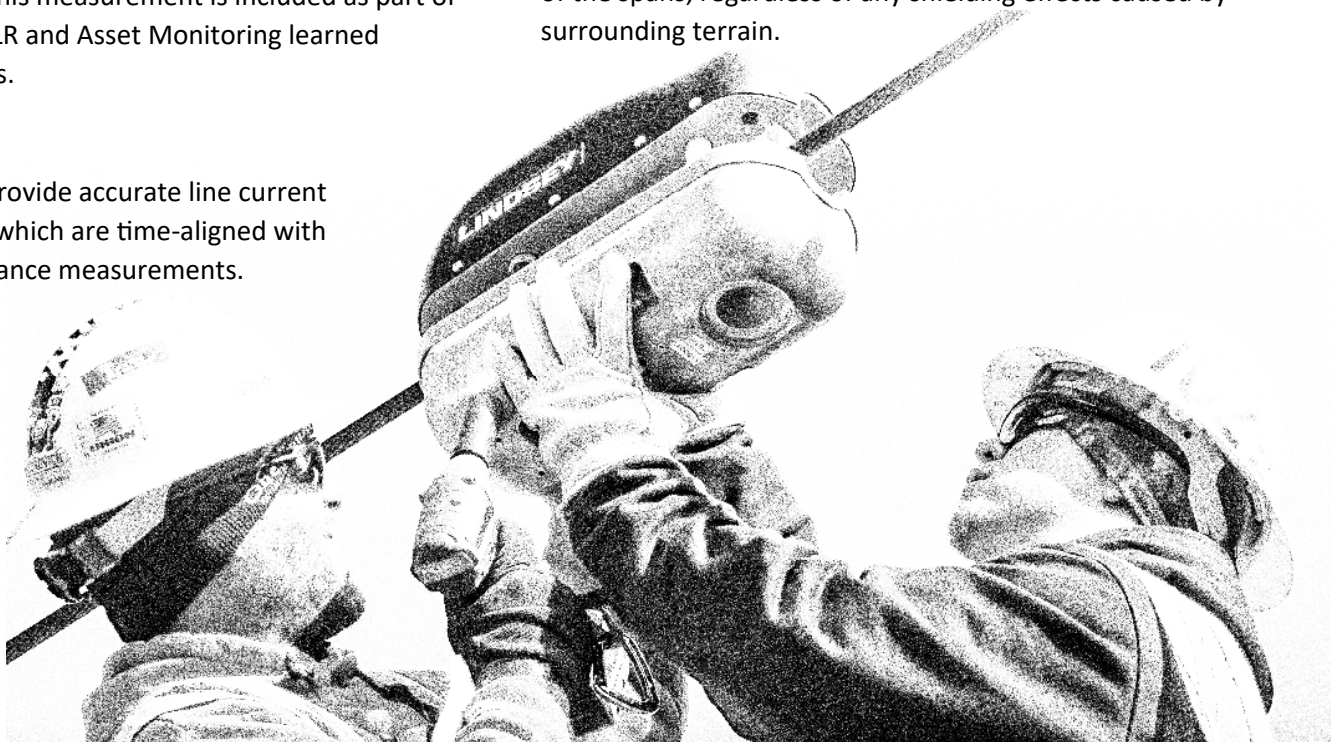
TLM monitors provide accurate line current measurements which are time-aligned with conductor clearance measurements.

Self-Powered, Simple Installation

TLM Monitors are self-powered by line current as low as 50A. Installation can be accomplished quickly by using hot stick, helicopter, or bare hand practices. Lines do not have to be de-energized for installation. No modifications to transmission towers or insulator/hardware assemblies are required. The TLM monitor is suitable for use on bundled conductors.

Conductor Span Temperature

Accurate conductor temperatures are important to develop accurate dynamic line ratings. No conductor models are required as SMARTLINE's learning algorithms develop as-built models of conductor behavior for each monitored span. Combined with direct distance to ground measurements, these models compute the averaged effective conductor temperature across the length of the spans, regardless of any shielding effects caused by surrounding terrain.

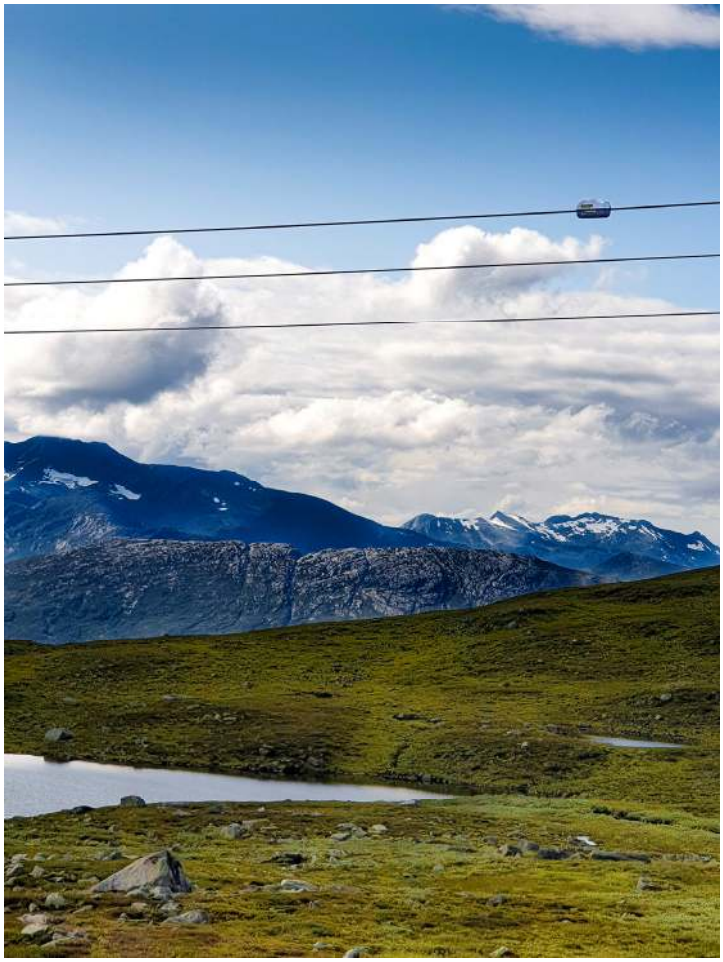


Choose from Cellular or Satellite Communications

TLM® monitors are available with either cellular or Iridium satellite communication options. All monitors are pre-configured to ensure hands-free communication upon power-up.

Cellular Communications

For those who prefer cellular communications, TLM monitors are available with a built-in global Tri-Band LTE-FDD and Dual-Band GPRS/EDGE modem which supports LTE CAT-M/NB-IoT protocol. Lindsey provided cellular phone service provides coverage in most countries.



The TLM monitor measures conductor sag via inclination and uses built-in LiDAR to directly measure the distance from the conductor to the ground below.

Photo Courtesy of Statnett:
Pilot project in Norway

Satellite Communications

Built-in Iridium satellite radio ensures reliable communications in even the most remote locations with no dependence on any other infrastructure. Use of the Iridium satellite network requires no other hardware to be installed on the line other than the TLM monitors, and requires no other effort as is typically associated with an RTU. TLM monitors are factory configured for immediate connection to the Iridium network after installation on a transmission line.

Specifications

Parameter	Specification
Conductor current nominal	50 - 1500A*
Conductor voltage	765kV L-L max
AC voltage frequency	50Hz - 60Hz
Conductor temperature	356°F (180°C) max
Conductor size	0.5 - 1.8” (13-46mm)
Conductor type	Aluminum or copper
Power on line current	80A
Minimum line current	50A
Tilt-pitch	-90° to +90°
Angle-roll	-90° to +90°
Height sensor distance	328ft (100m) max
Height sensor accuracy	+/- 4” (+/- 100mm)
Operating ambient temperature	-40 to +158°F (-40 to +70°C)
Applicable safety standards	EN 61010-1: 2010, AMD1:2016, EN 61010-2-30
Dimensions	16.5” (L) x 6.75” (W) x 8.75” (H) (420mm x 170mm x 220mm)
Weight	17 lbs (7.7kg)

*Per conductor. If applicable, SMARTLINE automatically scales the measured conductor current by the number of bundled conductors.

SMARTLINE-DLR™ Software: RATE

Dynamic Line Rating, or DLR, is a transmission line's actual real-time power carrying capacity based on real-time conductor and weather conditions along with knowledge of conductor behavior.

A line's DLR is typically 10 - 25% higher than a line's static (or base) rating. This additional capacity is usually available 95% of the time. DLR capacity provides opportunities in economic dispatch, trading, operations, and congestion mitigation.

The Next Generation of DLR

Dynamic line ratings must ensure a line's electrical clearance-to-ground would not be violated if the line was operating at its DLR value. The rating must also ensure the conductor does not overheat, which would result in thermal damage and permanent weakening of the conductor.

- SMARTLINE-DLR uses continuous line clearance and conductor inclination monitoring to ensure clearance-to-ground limits are not exceeded.
- SMARTLINE-DLR uses averaged conductor span temperatures to track the thermal performance of the line. Validated by direct temperature measurements, the system ensures thermal limits are not exceeded.
- Learning-based algorithms actively learn line behavior, resulting in much more accurate ratings than other methods. This technique properly reflects "as-built" line conditions compared to using "as-designed" assumptions.

The combination of learning-based conductor behavior models and direct measurements of critical conductor parameters make SMARTLINE-DLR line ratings unmatched.

Steady State and Transient Ratings

SMARTLINE can provide both continuous and transient dynamic ratings. Continuous ratings allow lines to be operated safely, efficiently, and economically on a day-to-day basis. Transient ratings refer to the short term ratings needed to respond to emergency conditions for specific periods of time without risking violation of dictated clearance requirements. SMARTLINE-DLR can be configured to provide either or both types of rating depending on your systems' requirements.

DLR or AAR?

Only DLR provides situational awareness



Seasonally adjusted ratings (SAR) and ambient adjusted ratings (AAR) are commonly used to increase a line's static rating. These techniques acknowledge different prevailing ambient temperature conditions exist at different times of the year. However, they ignore the impact of wind, which has a significantly greater impact on line ratings than ambient temperature.



Further, the recommendation that wind speed assumptions should be reduced when considering lower ambient temperatures* is usually ignored, increasing the risk associated with AAR and SAR.

Dynamic line rating is a transmission line's actual, real-time, power carrying capacity. Using real-time measurements, DLR takes into account all weather parameters including ambient temperature, wind speed, wind direction, and solar radiation, as well as actual line behavior, including clearance to ground and conductor temperature. Dynamic line rating provides the situational awareness of a line's actual rating.

* "GUIDE FOR SELECTION OF WEATHER PARAMETERS FOR BARE OVERHEAD CONDUCTOR RATINGS," CIGRE, CIGRE and IEEE Joint Task Force Working Group B2-12, August 2006, Section 1.5.3.1

SMARTLINE-TCF™ Software: FORECAST

SMARTLINE-TCF builds on the learned line behavior models and dynamic line rating capabilities of SMARTLINE-DLR™ to develop highly accurate forecasts of transmission line power carrying capacity.

Firm, Fixed Forecasts

Firm transmission line power capacity forecasts can be provided from 1-hour to seven days ahead. For example, a 2-hour forecast indicates the line may be operated at the forecast level for the next two hours, while a 24-hour forecast allows operation at the forecast level for the next 24 hours.

Flexible Forecast Scheduling

Forecasts can be scheduled to be run once a day, or updated periodically. For example, a 12-hour forecast could be run once at midnight and then be updated hourly starting at 8 am.

Forecast Bundles

Sets of forecasts can be set to run on a regular basis. Define one set of forecasts to support the day-ahead market, another for the real-time market, and another for transmission engineering and planning departments.

High Confidence

By default, SMARTLINE-TCF forecasted ratings are set to ensure a 98% confidence factor is achieved for the forecast rating. This means the instantaneous DLR during the forecast period has only a 2% likelihood of being below the forecast rating for that moment in time. If desired, higher or lower confidence factors may be used.

Clearance Compliant

The use of real-time measurements of conductor clearance-to-ground and conductor sag ensures forecast ratings maintain compliance to clearance limits in addition to adhering to conductor thermal limits.

Selective Data Presentation

SMARTLINE-TCF provides detailed interactive graphic display for engineering analysis, simple numeric display for EMS operator screen display, and flexible discrete data import into EMS systems.

Why Transmission Line Capacity Forecasting?

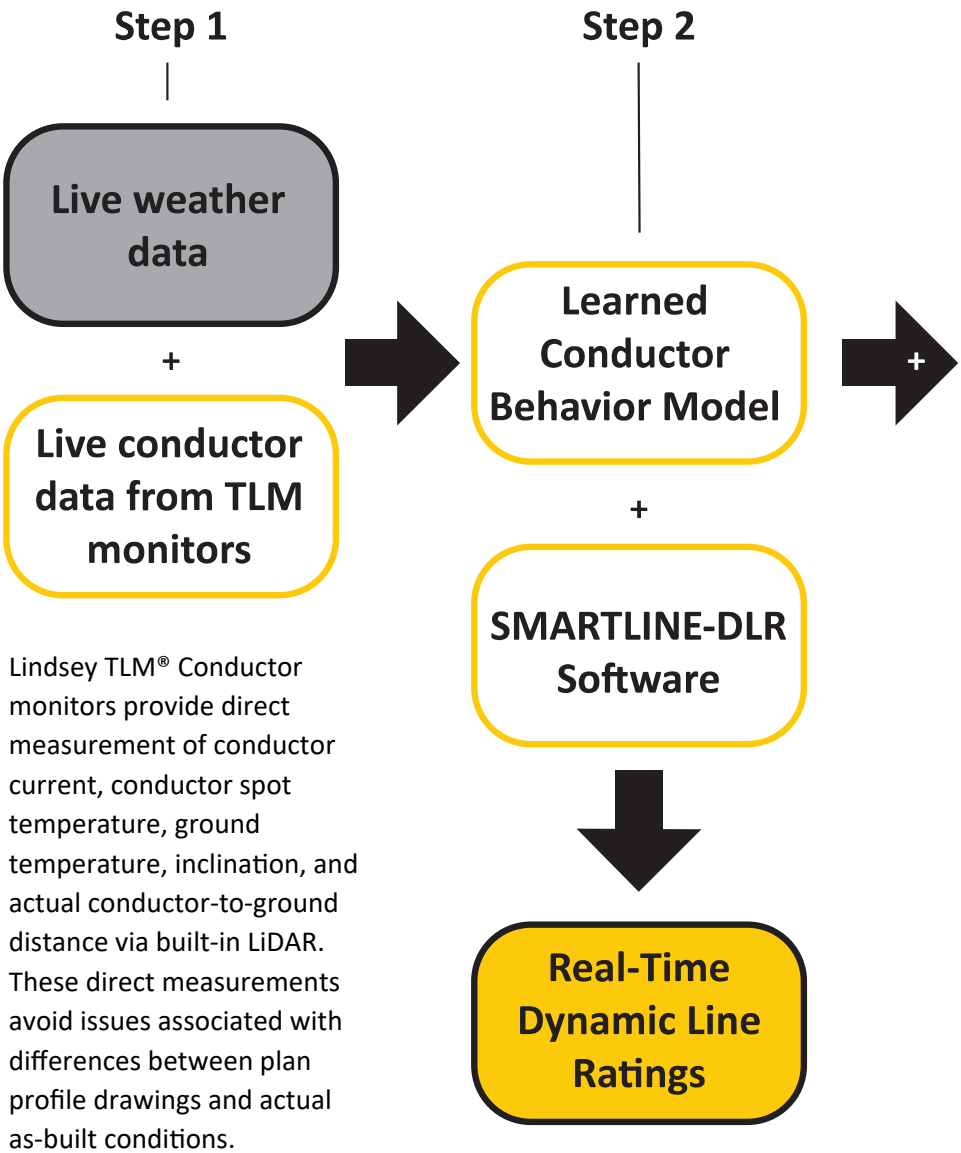
Forecasting is not the same as DLR

DLR is a transmission line's real-time power carrying capacity. SMARTLINE-TCF builds on the situational awareness provided by DLR and provides stable forecasts of transmission line power carrying capacity with a very high confidence factor. Unlike the more variable nature of DLR, the stability and high confidence factors of these forecast ratings make them suitable for a wide range of operational applications.

Numerous studies have shown this additional capacity provides opportunities in economic dispatch, trading, operations, and congestion mitigation. Application of DLR and forecasting are powerful tools for improving contingency planning, cost effectively addressing lines with slow load growth, and deferring or eliminating the need for line upgrades or reconductoring.

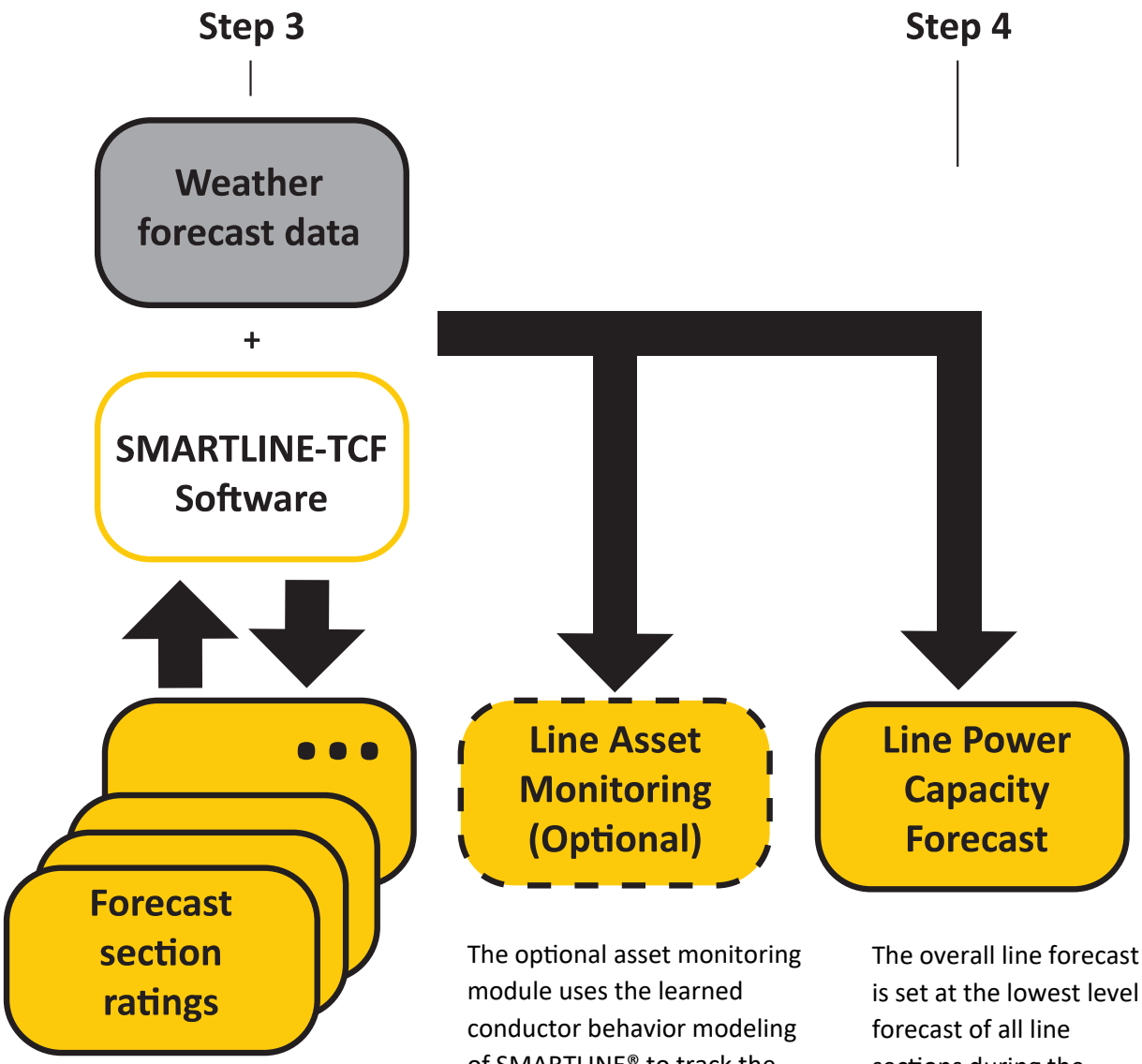
LINDSEY SYSTEMS

The SMARTLINE® Process



Lindsey TLM® Conductor monitors provide direct measurement of conductor current, conductor spot temperature, ground temperature, inclination, and actual conductor-to-ground distance via built-in LiDAR. These direct measurements avoid issues associated with differences between plan profile drawings and actual as-built conditions.

SMARTLINE-DLR™ is the underlying DLR software that feeds SMARTLINE-TCF™. As-built conductor behavior models are learned for each span using real-time data and measured parameters. Instantaneous DLR ratings are developed using real-time weather data and data computed from the learned behavior models. No assumed conductor models are used, resulting in consistent, less sporadic ratings.



The SMARTLINE-TCF™ software develops future DLR ratings for the desired forecast time-period based on forecasted weather data. These are compared to the corresponding instantaneous DLR at the forecasted time. Statistical analysis of the results over time allows SMARTLINE-TCF to generate forecasts with a 98% confidence factor. Forecasts are generated for each monitored line section.

The optional asset monitoring module uses the learned conductor behavior modeling of SMARTLINE® to track the effects of mechanical loading events on the conductor. This module provides a real-time indication of loss of strength based on conductor creep.

The overall line forecast is set at the lowest level forecast of all line sections during the forecast window.

Conductor Asset Monitoring (Optional): MONITOR

Predicting conductor lifecycle is a difficult task. Often, such analysis only takes place after one or more failure events on a transmission line. At this point, it is too late to avoid outages or to allow for proactive capital budgeting and project planning.

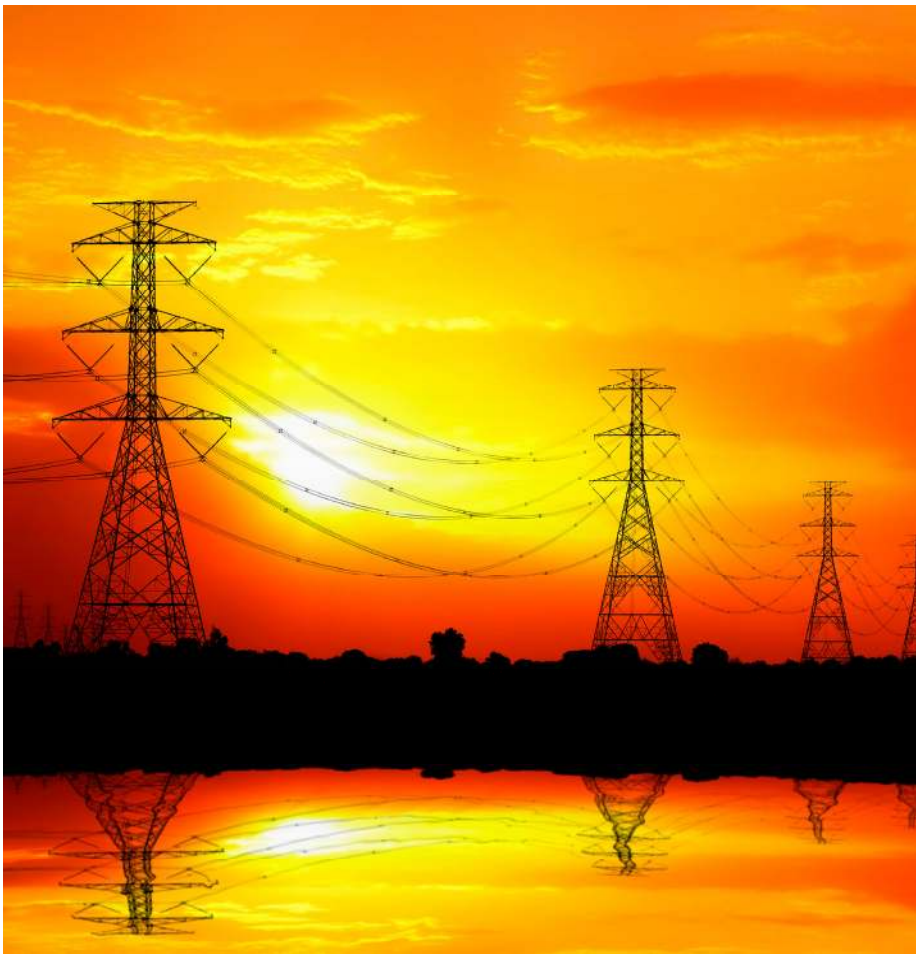
The optional Conductor Asset Health module for SMARTLINE® system provides an accurate, live assessment of conductor life. The learning-based conductor behavior model used by SMARTLINE allows the system to track conductor life as a percentage of the conductor's maximum lifecycle creep. The result is shown in an intuitive bar graph for each monitored span.

Establishing a Baseline

SMARTLINE systems are generally installed on existing lines, where years of operational loading and exposure to the environment has typically resulted in loss of conductor strength. This loss of strength introduces creep (or elongation of the conductor) over the conductor's initial "no creep" condition. During system set-up, Lindsey engineers will analyze the line design including PLS-CADD models and LiDAR scan data as available, to determine the line's final design creep level and its ultimate design creep. The latter typically reflecting a 10% loss in strength. However, SMARTLINE allows the user to specify the residual strength criterion.

Dynamic Modeling

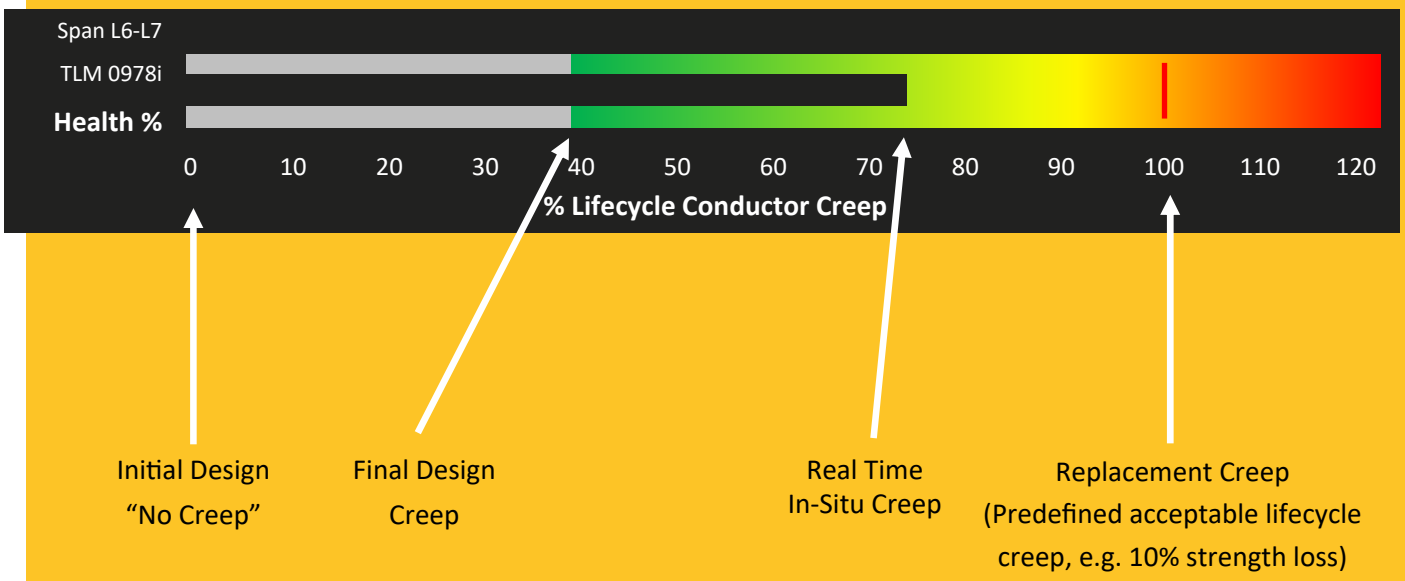
SMARTLINE mitigates risk by monitoring conductors for optimal replacement while maximizing the life of each conductor. TLM® conductor monitors installed along the line provide continuous sensing of the conductor's behavior. The dynamic modeling provided by SMARTLINE provides a reliable indicator of where the conductor is along its normal creep lifecycle.



Monitoring conductor life is vital for reliable system operation. SMARTLINE's Asset Health Module tracks the permanent elongation of conductors and the resulting loss of strength.

Event Related Aging

Specific events that affect a conductor's life, such as galloping, major ice loading, and wildfires, will be reflected by more discrete changes in creep. SMARTLINE identifies these events when the clearance-based conductor behavior and conductor inclination models both indicate increases in creep. SMARTLINE includes these events in determination of conductor health.



Intuitive Conductor Aging Indicator:

Conductor creep is the permanent elongation a conductor experiences over its life and is related to loss of strength. SMARTLINE® provides an intuitive display showing the current status of the conductor's aging process as related to conductor creep. As loading conditions over the life of a transmission line will affect each span differently, SMARTLINE provides this display for each monitored span.



Data Security and Interfaces

SMARTLINE® is designed as a highly secure system that is easy to integrate into utility applications, which provides useful graphical tools for engineering analysis.

Cyber Security

- TLM® monitors are inherently cyber secure.

⇒ Monitors are installed mid-span on the HV transmission line and are not accessible for physical attack as compared to RTUs, ground-based or tower-based sensors, and/or radios.

⇒ Iridium-based TLM monitors have no on-board communication port or SIM card and provide no terrestrial path to the data server.

⇒ Iridium based communication is inherently secure due to its use of naturally short messages, non-continuous transmission, doppler frequency shifts and short beam handover time.

⇒ Cellular-based TLM monitors use TLS1.2 secret key encryption algorithms to provide end-point authentication and communication security over IP.

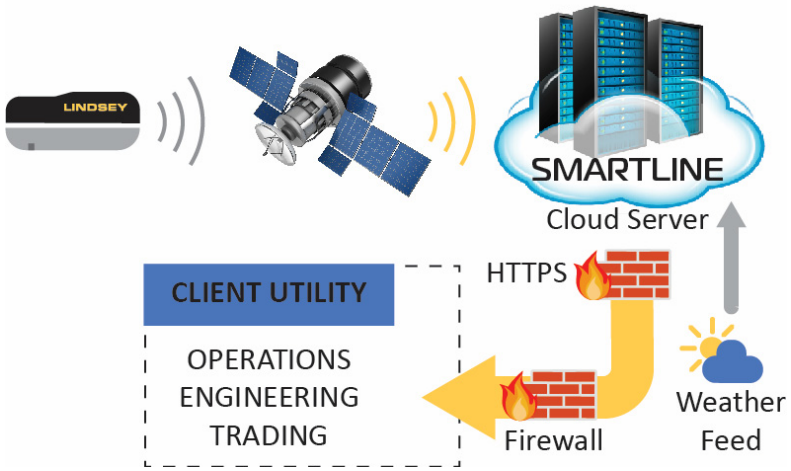
- Two-factor authentication ensures access is granted only to the person authorized. SMARTLINE provides for unlimited users.
- Regular penetration testing assesses the effectiveness of SMARTLINE's security controls by simulating real-world cyber-attacks.
- All databases and software have full redundant backup ensuring minimal disruption in the event of failure.
- Independent databases are maintained for all customers ensuring no commingling of data.

Graphical User Interface

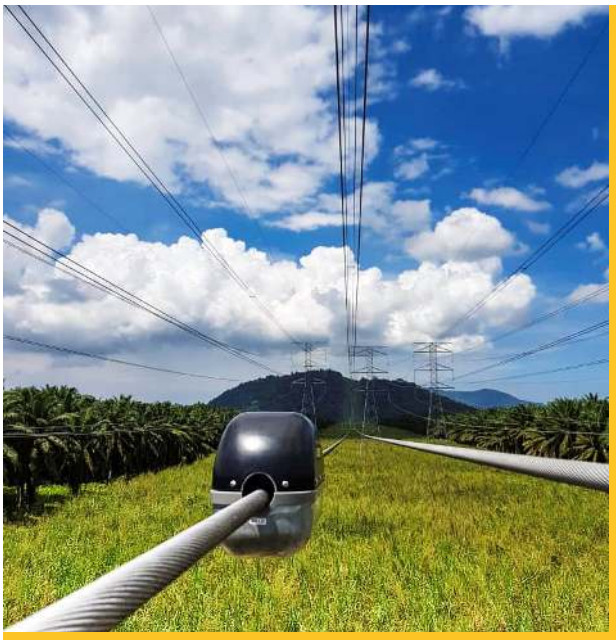
- Graphical representation of all line and weather data and forecasts are provided for engineering analysis. All data can be downloaded in convenient CSV or JSON formats for off-line analysis.
- View output by line or individual TLM monitor output. View forecasts for each line section or for the overall line.

Application Programming Interface Included

- SMARTLINE includes an easy to use application programming interface (API) which allows for quick integration into EMS, asset management systems, and other critical applications.
- The interface has been designed as a RESTful API that uses https requests to collect data using less bandwidth than other methods making it ideal for internet usage.



The direct-to-satellite communications provided by Iridium-based TLM monitors is ideal where existing communications infrastructure is either not available or less than ideal.



About Lindsey Systems

Lindsey Systems is recognized globally as an innovator in the electric power industry. As a supplier of systems, products, and product solutions for the transmission and distribution of electricity, Lindsey enables utilities to meet the challenges of the modern-day electrical grid.

With 75 years of experience and a reputation as a thought leader in the industry, Lindsey Systems' products are known around the world for reliability and performance.

Lindsey is ISO-9001, ISO-14001, ISO-27001, and CSA W47.2 Certified.

For more information, visit www.Lindsey-USA.com.

Thoughtful Solutions in Transmission Line Monitoring

Lindsey Manufacturing Co., dba Lindsey Systems
760 N. Georgia Avenue | Azusa, CA 91702 USA
Tel. +1-626-969-3471 | www.lindsey-usa.com

©2024 Lindsey Systems, Lindsey, SMARTLINE, SMARTLINE-DLR, SMARTLINE-TCF, and TLM are trademarks or registered trademarks of Lindsey Manufacturing Co.
Iridium is a trademark of Iridium Communications Inc.
U.S. Patents 7,786,894 and 8,738,318 and other U.S. and foreign patents pending.

Publication Number 11B-002 SMARTLINE-TCF • February 2024