Environmental Monitoring for Dynamic Line Rating

Energy management

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Introduction & Context

What is Dynamic Line Rating (DLR) and why is it important

Power lines have a maximum current they can safely carry without overheating or being damaged. This limit is called the **line rating**.
Traditionally, the **Static Line Rating (SLR)** has been used: a fixed and very conservative value, calculated by assuming "worst-case" environmental conditions (e.g., high temperature, weak wind, strong solar radiation).

In reality, these extreme conditions occur only rarely. Most of the time, the line operates in much better conditions and could carry more power than the static rating allows.

Dynamic Line Rating (DLR) was created to unlock this hidden potential.
It is a method that updates the line capacity in real time, based on environmental measurements (wind, temperature, solar radiation) and the actual operating conditions.

In practice, if the weather is cool and windy, the conductor is cooled more effectively and can safely carry more current.

Difference between SLR and DLR

SLR → A single fixed value, set conservatively, valid all year round. Safe, but often underutilizes the line.

DLR → A dynamic value that changes hour by hour, even minute by minute, reflecting the actual conditions of the line and the weather

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Key benefits of DLR

Greater transmission capacity
Increases up to +20–30% in favorable conditions, without building new lines.

Grid optimization
Reduces congestion and makes better use of existing assets.

Renewable integration
Enables more solar and wind energy to be fed into the grid, avoiding curtailment due to static limits.

DLR Operating Principles

The current flowing through a transmission line generates heat due to the **Joule effect** *(When an electric current passes through a conductor, the electrons encounter electrical resistance. This resistance converts part of the electrical energy into heat: this is the so-called Joule effect.)*.

If this heat is not dissipated, the conductor temperature increases, leading to risks such as loss of mechanical strength or excessive sagging of the line (SAG effect).

Excessive bending of the cables also represents a safety problem related to the minimum height that it must reach from the ground

The conductor's temperature is therefore the result of a **thermal balance** between:

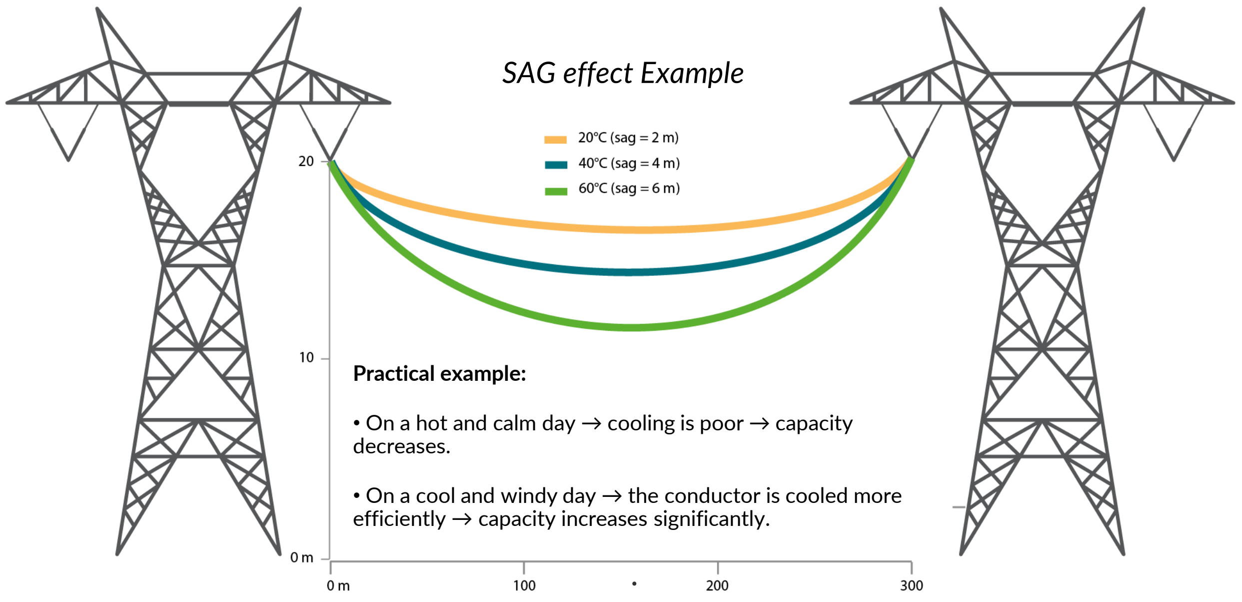
Heating sources:

- Joule heating (I^2R losses, proportional to current)
- Solar radiation (direct heating from the sun)

Cooling mechanisms:

- Wind convection (the most influential factor)
- Ambient air temperature (cooler air enhances heat exchange)

When heating and cooling are balanced, the conductor reaches a stable operating temperature. The **line rating** is the maximum current that keeps this temperature within safe limits.



Static vs Dynamic Rating

Static Line Rating (SLR): assumes fixed and conservative conditions (e.g., 35°C, weak wind, strong solar radiation). The line is always rated as if it were operating under worst-case conditions.

Dynamic Line Rating (DLR): continuously updates the maximum capacity based on real-time measurements of wind, ambient temperature, and solar radiation.

Role of Weather Sensors

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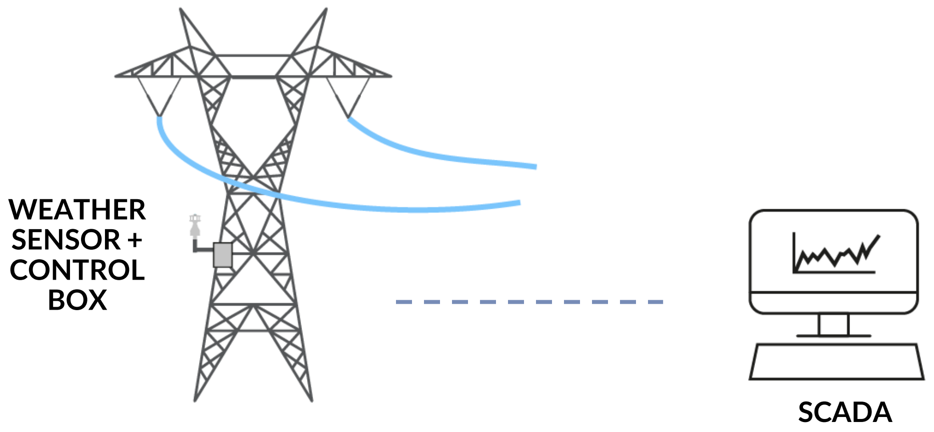
The core of Dynamic Line Rating is the ability to calculate the actual conductor temperature and therefore its safe carrying capacity. To do this, reliable environmental data is essential, because it is the weather conditions that determine whether the line is cooled or overheated.

The key parameters are three:

• **Wind speed and direction** → the most important factor for cooling. Even moderate wind, if oriented well with respect to the line, can significantly increase the available capacity.

• **Air temperature and humidity** → the baseline condition: the cooler the air, the more efficient the heat exchange.

• **Solar radiation** → factors, but useful to refine the calculation. For example, on a clear sunny day, radiation can increase the conductor temperature.”



MODEL-BASED VS REAL DATA APPROACH

“It is important to distinguish between relying only on models and using real sensor data in the field.

• **Theoretical models** → can estimate line capacity based on historical or average climate data. They are useful, but limited: if not calibrated on local conditions, they risk being too conservative or, conversely, too optimistic.

• **Field sensors** → provide real, real-time measurements, reducing uncertainty. With direct sensor data, the DLR system becomes much more accurate and safe, because it is based on reality rather than assumptions.

Conductor → Weather sensor → DLR software → SCADA → Operator

• The conductor is subject to heating and cooling.

• The weather sensor measures the actual environmental conditions.

• The DLR software processes this data and calculates the available capacity.

• The SCADA system receives the results and makes them available to grid operators for real-time decision making.

Ultrasonic anemometer and weather sensor [HD52.3DP17R]

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Ultrasonic anemometers provide accurate and reliable measurements of wind speed and direction using sound waves rather than mechanical components. This makes them ideal for applications that require high accuracy and low maintenance, such as meteorology, air quality monitoring, and industrial processes.

The ultrasonic anemometer is equipped with multiple transducers, which act as both emitters and receivers of ultrasonic sound waves. These transducers are usually arranged in opposite configurations on a structure. The transducers emit pulses of ultrasonic sound waves that travel through the air to an opposing transducer; wind speed affects the travel time of the sound waves. When the wind blows in the same direction as the path of the sound wave, the wave travels faster. When it blows in the opposite direction, the wave travels slower.

They are more resistant to extreme weather conditions, such as frost, dust and high humidity, making them suitable for prolonged outdoor use.

One type of sensor for various measurements

Ultrasonic anemometers, on the other hand, use acoustic sensors that detect changes in sound wave propagation caused by air movement in real time. This method allows both wind speed and direction to be determined simultaneously with great accuracy, eliminating the need for multiple devices. Reducing installation and management costs

independent, accurate reading

Ultrasonic sensors offer high accuracy and speed in measurements, even in situations where the wind is weak or the atmosphere is particularly turbulent. Thanks to their advanced technology, they can detect air movements with great sensitivity, ensuring reliable data under all conditions.

Less maintenance

The absence of mechanical friction and resistance to weathering ensure a long service life for the device, maximizing the return on investment.
Suitable for remote installations, in hard-to-reach locations, such as weather stations in remote areas or offshore wind towers, low maintenance significantly reduces the number of field interventions

Sensor : HD52.3DP17R

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ACCURATE & RELIABLE

All instrument sensors are factory calibrated and do not require additional interventions of the user.

LOW POWER CONSUMPTION

Ideal for installation in remote sites it can be powered by photovoltaic panel and backup battery

GREAT FLEXIBILITY

Wide variety of outputs choice.

EASY TO SET UP & QUICK TO INSTALL

Easy mounting & alignment facilitated by built-in compass. Configuration and real time data monitoring via software

ALL-IN-ONE COMPACT AND LIGHT

All main quantities of meteorological interest combined in a single instrument

AVAILABLE WITH
ACCREDIA ISO-17025
CALIBRATION CERTIFICATE

Air speed

Unique in Italy, with two closed-cycle Göttingen-type wind tunnels, for air speeds of up to 60 m/s.

Sensor : HD52.3DP17R

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WIND SPEED/DIRECTION

Wind speed	
Sensor	Ultrasounds
Measuring range	0…60 m/s (0…50 m/s with rain gauge option)
Resolution	0.01 m/s
Accuracy	± 0.2 m/s or ± 2%, the greatest (0…35 m/s), ± 3% (> 35 m/s)
Wind direction	
Sensor	Ultrasounds
Measuring range	0…359.9°
Resolution	0.1°
Accuracy	± 2° RMSE from 1.0 m/s

GENERAL

General features	
Power Supply	10…30 Vdc
Power consumption	26 mA @ 24 Vdc without heater 8 W @ 24 Vdc with heater
Serial outputs	RS232, RS485 (¼ Unit Load), RS422 and SDI-12
Communication protocols	NMEA, Modbus-RTU, SDI-12, proprietary RS232 and RS485
Analog outputs	2 analog outputs, for wind speed and direction. Output at choice among 4…20 mA (standard), 0…1 V, 0…5 V and 0…10 V (**option 0…10 V needs 15…30 Vdc power supply**)
Wind speed averaging interval	Configurable from 1 s to 10 min
Electrical connection	19-pole M23 male connector
Operating temperature	-40…+70 °C Minimum temperature for the rainfall sensor 1 °C
Protection degree	IP 66
Survival speed	90 m/s (60 m/s with rain gauge option)
Weight	About 1 kg (version HD52.3DP147) About 1.5 kg (version HD52.3DT147)
Case	Plastic material. Metal parts: AISI 316

SOLAR RADIATION

Solar radiation (*needs option* ***P***)	
Sensor	Thermopile
Measuring range	0…2000 W/m²
Resolution	1 W/m²
Accuracy	Class C pyranometer

AIR TEMPERATRURE/HUMIDITY

Air temperature (*needs option* ***17***)	
Sensor	Pt100
Measuring range	-40…+70 °C
Resolution	0.1 °C
Accuracy	± 0.15 °C ± 0.1% of measurement
Relative humidity (*needs option* ***17***)	
Sensor	Capacitive
Measuring range	0…100%RH
Resolution	0.1%
Accuracy (@ T = 15…35 °C)	± 1.5%RH (0…90%RH), ± 2%RH (remaining range)
Accuracy (@ T = -40…+70 °C)	± (1.5 + 1.5% of measurement)%RH

HD52.3D

Analog output
Blank = 4…20 mA (default)
V = 0…10 V
V1 = 0…1 V
V5 = 0…5 V

Heating
Blank = without heating (default)
R = with heating

Temperature
Blank = without (default)
7 = with Temperature (*option 1 'RH' required*)

Atmospheric Pressure
Blank = without (default)
4 = with Atmospheric Pressure

Relative Humidity
Blank = without (default)
1 = with Relative Humidity (*option 7 'Temperature' required*)

P = Pyranometer
K = Bird Spike
Blank = Without pyranometer and/or bird spike

Customer Segments & Market

Dynamic Line Rating is not a niche technology – it is relevant to many players in the power sector.

The first natural customers are the **TSOs, Transmission System Operators**. For them, DLR is especially valuable because it increases the capacity of high-voltage backbones without the need to immediately build new lines, thus reducing congestion and improving grid resilience.

The second group are the **DSOs, Distribution System Operators**. Even at medium- and low-voltage levels, load variability and the growth of distributed generation require dynamic tools. DLR allows DSOs to better integrate local renewable production and manage demand peaks.

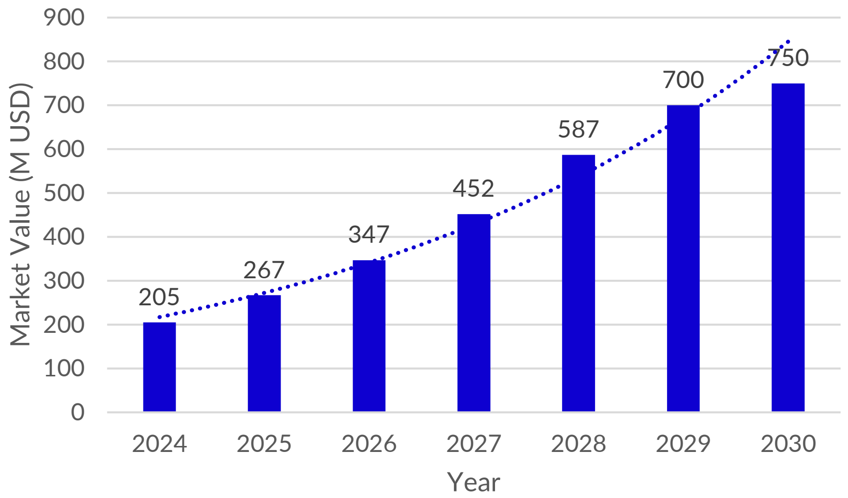
Then we have the **integrated utilities**, which produce, transmit, and distribute electricity. For these companies, DLR is a way to optimize assets across the entire value chain.

Renewable operators, particularly wind and solar farms, are also key stakeholders. These plants are often connected in remote areas where grid capacity is limited. DLR reduces the risk of renewable output being curtailed due to static grid constraints.

Finally, there are the **regulators and pilot projects**, which play a strategic role. They are often the first to fund or promote innovative initiatives for the energy transition and grid modernization.

Today the DLR market is still relatively young, but it is expanding very quickly.

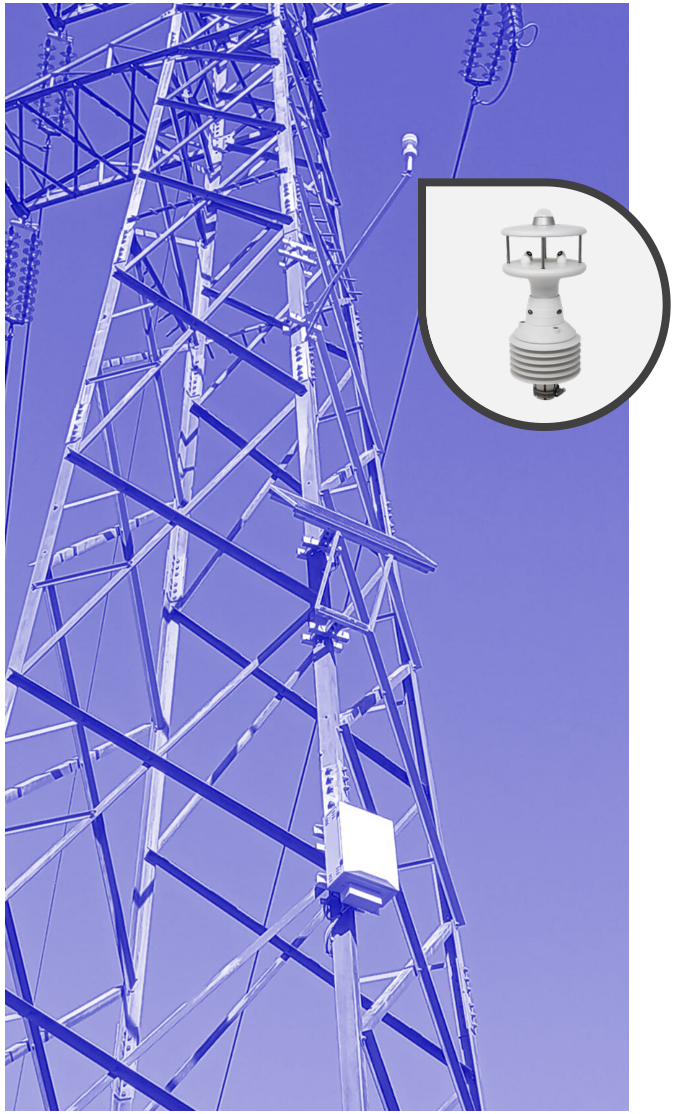
In 2024, the global market value is estimated at around **USD 205 million**, and forecasts suggest it could exceed **USD 750 million by 2030**.



Annual growth rate (CAGR) **30%**

This growth is driven by two major forces. On the one hand, the increasing share of renewable energy, which makes the grid more variable and in need of flexibility. On the other hand, regulatory and political pressure to optimize the use of existing infrastructure, avoiding costly and lengthy new line projects

Use Case Example



Scenario 1 – Hot day, no wind

Let's imagine a hot summer day, with temperatures around 35–38 °C and no wind.
In this situation, the conductor cools down very poorly. The heat generated by the current is not dissipated efficiently, so the conductor temperature rises quickly.

With **Static Line Rating (SLR)**, the line capacity is fixed conservatively for exactly this type of worst-case condition.

With **Dynamic Line Rating (DLR)**, the system confirms that the line capacity is actually **reduced**, because the environmental conditions are unfavorable. This makes the operation safer: it prevents overheating and excessive sag

Scenario 2 – Cool, windy day

Now let's take the opposite situation: a cool spring day, with 15 °C ambient temperature and a steady crosswind of 6–8 m/s.

Here, the conductor benefits from excellent natural cooling: both the low temperature and the wind help dissipate the heat generated by the current.

Under **SLR**, the line would still be limited to the same conservative fixed value.

But with **DLR**, the operator sees that the line can safely carry **20–30% more current** than the static rating, unlocking hidden capacity without building new infrastructure

Typical Q&A

Q1. How much can capacity increase with DLR?

In favorable conditions, such as cool and windy days, DLR can unlock an additional **20–30% of transmission capacity** compared to the static rating. Of course, the exact gain depends on the specific line, the local climate, and the installation setup

Q2. Is it safe to rely on weather data?

Yes, it is safe, provided that reliable sensors are used. Weather conditions are the primary drivers of conductor cooling, so measuring them in real time is the best way to know the true capacity of a line. In fact, DLR does not reduce safety; on the contrary, it **increases it**, because it lowers the rating under unfavorable conditions, rather than relying on a fixed assumption

Q3. How many sensors are needed per line?

“It depends on the length and criticality of the line. A short line might only need **one sensor station**, while longer or strategically important lines may require **multiple sensors distributed along the route** to capture local variations in weather and wind. The configuration is usually optimized case by case

Q4. Does it require maintenance?

Modern ultrasonic weather sensors, such as the HD52.3DP17R, are designed to be **robust and low-maintenance**. They have no moving parts, so they don’t suffer from mechanical wear. In general maintenance requirements are minimal compared to traditional mechanical sensors senseca