Distributed vs. spot temperature measurements in dynamic rating of overhead power lines.

CO2 footprint reduction and efficiency increase using the dynamic rate in overhead power lines connected to wind farms.

University College of Dublin, 24th May 2019
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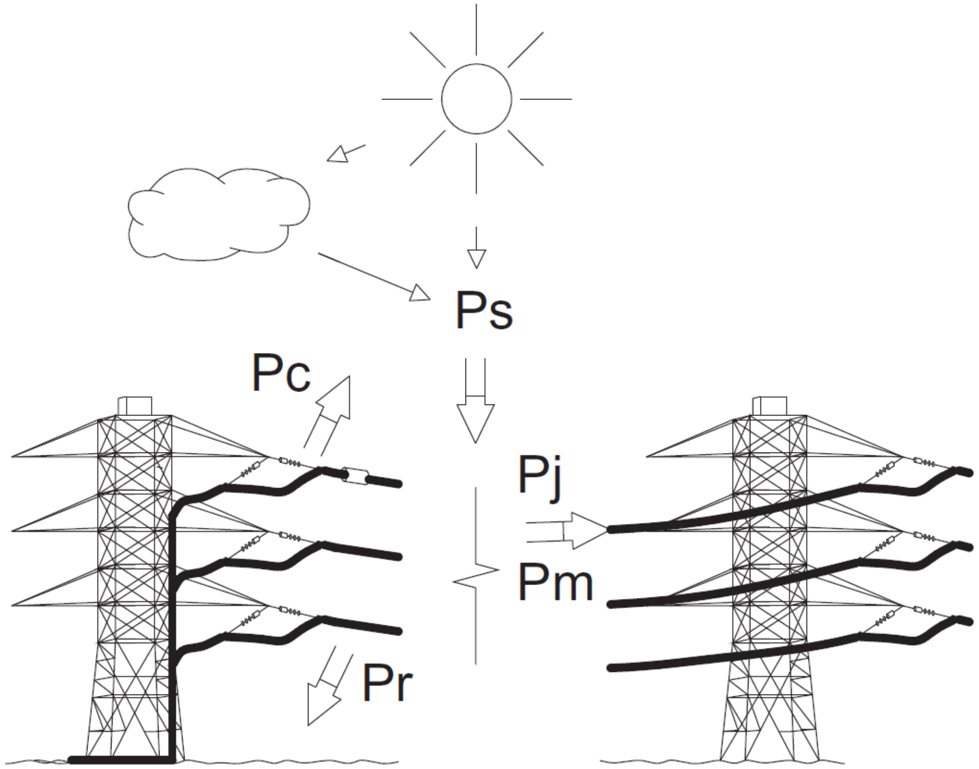
Introduction:

- The conductor **static rate is the maximum electrical current** that a conductor can continuously carry **without deterioration**.
- Calculated under constrained conditions resulting in **conservative load values and low-efficiency grids.**
- The **dynamic rate** is a result of studies on increasing power line capacity (ampacity) **considering the dynamic environmental conditions**.
- The **dynamic rate** is **limited by several factors**, as the **conductor structure** and design, the **environmental conditions** (ambient temperature, solar radiation, wind, etc.) and the **line operating conditions**.
- If conductor **cooling and heating processes are measured in real time**, the **maximum instantaneous current can be used** without reaching the maximum allowable conductor temperature.
- The working **parameters should be measured or estimated** using methods to calculate the ampacity. **CIGRE TB 601 and IEEE 738** are standards that describe the algorithms used to estimate the ampacity and temperature of a conductor.

Introduction:

Energy balance and ampacity calculation:



- Joule Heating (P_j)
- Magnetic Heating (P_m)
- Solar Heating (P_s)
- Convective cooling (P_c)
- Radiative cooling (P_r)

$$mc\frac{\Delta T}{\Delta t} = P_j + P_m + P_s - P_c - P_r$$

$$I = \sqrt{\frac{mc\frac{\Delta T}{\Delta t} - P_m - P_s + P_c + P_r}{R_{ac}}}$$

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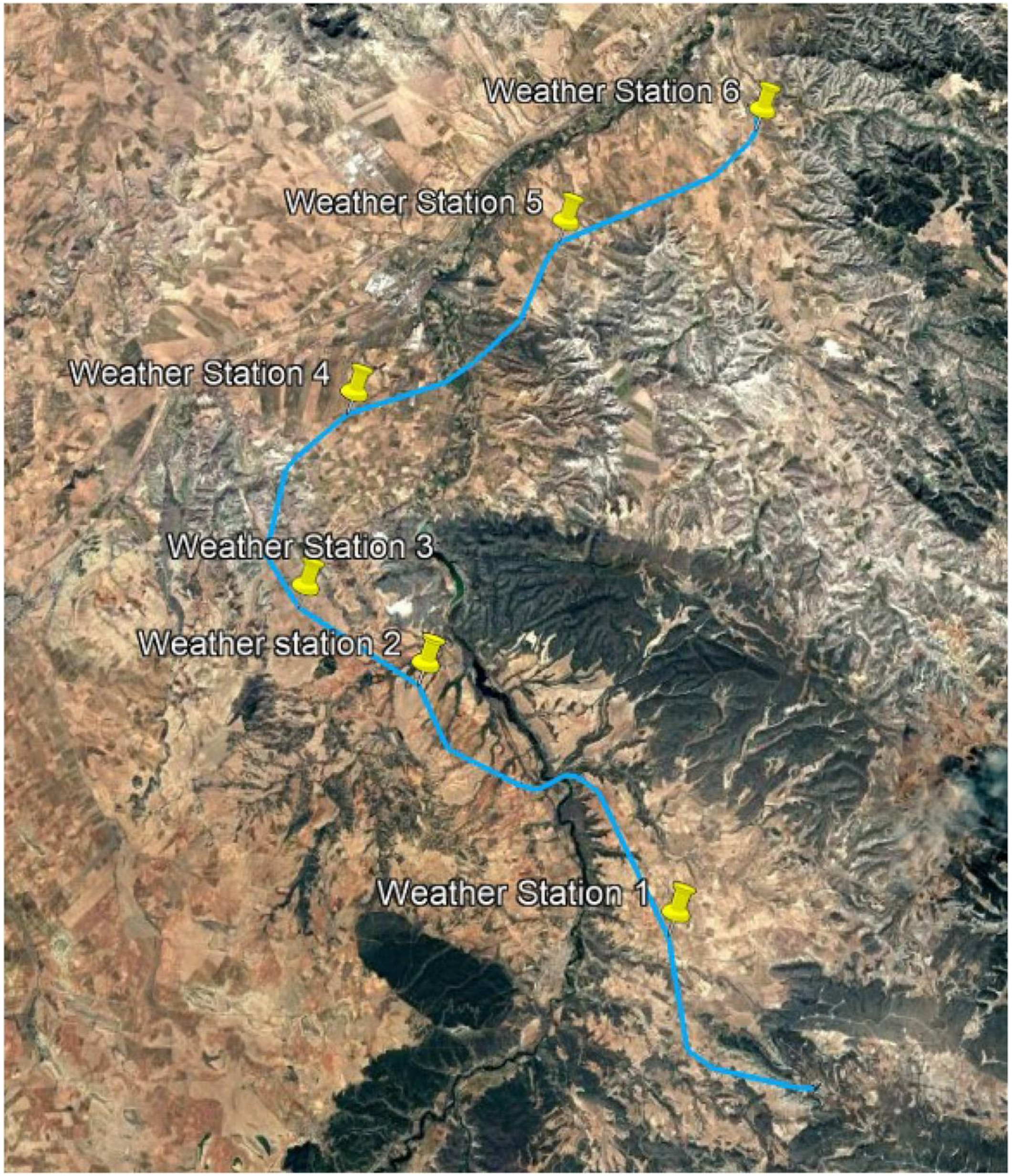
Case of study:

- **220 kV** line placed in the north-east of Spain with a **LA-455 conductor** and seasonal static rates (790 A spring, 730 A summer, 760 A autumn and 870 A winter).
- Length of approximately of **30 km**.
- The line has **6 weather stations** distributed along the line with ambient temperature, humidity, wind speed and solar radiation data are provided every 5 minutes.
- Additionally, this line has a **Distributed Temperature Sensor (DTS)** that monitors approximately 10,200 points along the line with a resolution of 2 m. The values of conductor temperature are provided approximately every 10 minutes.
- **6 areas of influence** are selected for each weather station corresponding to the orography of the surroundings.
- **From 10 September 2013 to 31 March 2014** environmental conditions and conductor temperature measurements were recorded.

Case of study:



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Goal:

- To estimate the **loss of accuracy when just spot temperature measurements can be recorded**, in this case one measurement close to each weather station, instead of having all the distributed thermal information.

- **To do so**, the average, maximum and minimum temperatures obtained in each area of influence by the **DTS were stored with 10 min resolution**. At the same time, the **closest DTS measurement to the weather stations were also stored**.

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Results:

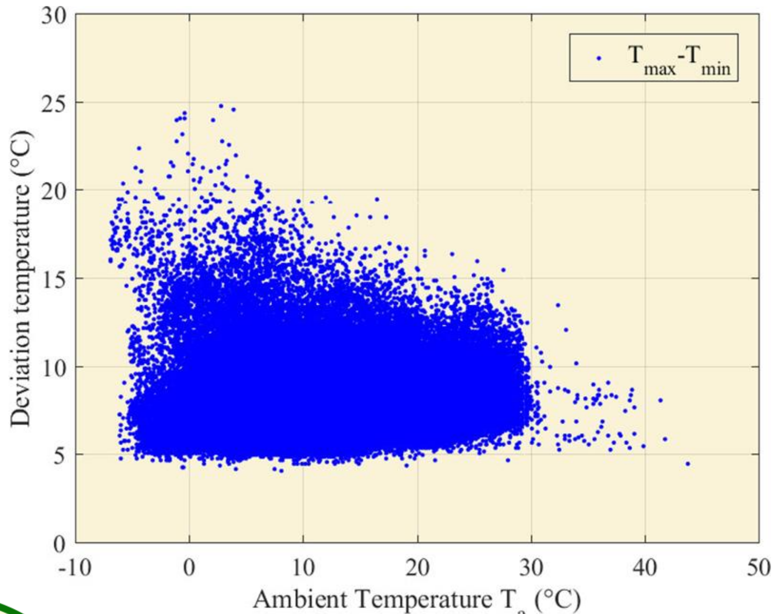
- The distributed temperature measurements are divided in the areas of influence of the 6 weather stations and **the average, T_{av}, the minimum, T_{min}, and the maximum, T_{max}, temperatures recorded in every area**.
- The **maximum temperature difference** detected between the maximum and the minimum temperature measurements in an area of influence **was 24.8 °C.**
- It can be noticed that the **minimum difference is between 4 and 5 °C** and the maximum between 17 and 25 °C.

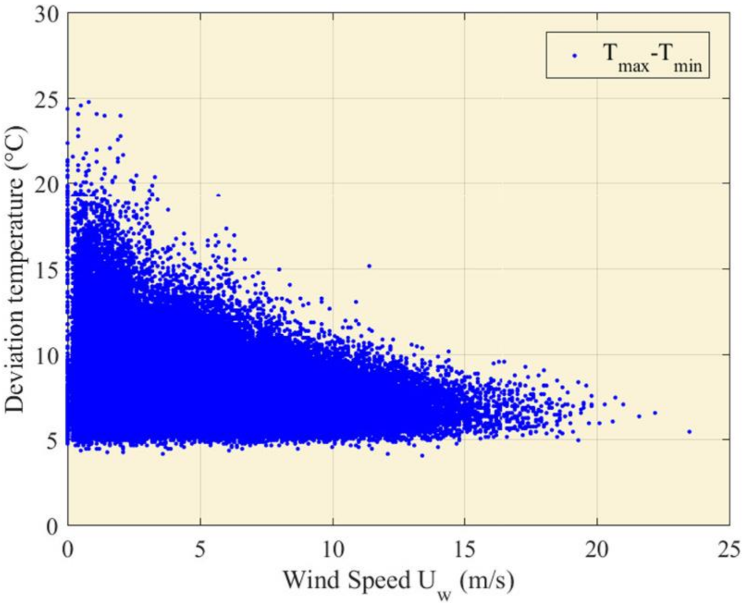
Maximum and minimum temperature differences.

Area	Max. diff.	T_{max}	T_{min}	T_{av}	Min. diff.	T_{max}	T_{min}	T_{av}
1	24.8	30.6	5.8	15.5	5.3	23	17.7	20.2
2	16.7	24.6	7.9	15.9	4.4	27.7	23.3	25.6
3	17.8	22.6	4.8	12.4	4.2	11.4	7.2	9.3
4	20.1	21.4	1.3	8.9	4.1	18	13.9	15.7
5	19.3	34.4	15.1	24.3	4.8	9	4.2	6.6
6	19.5	19.5	0	14.6	4.4	8.1	3.7	5.8

Results:

- The **difference increases as the ambient temperature decreases** and reduced when the ambient temperature increases.
- However, the **most critical parameter in the decrease of the difference** between the maximum and minimum temperature measured in an area of influence **is the wind speed**. As it increases, the distributed temperature tends to be more homogeneous.





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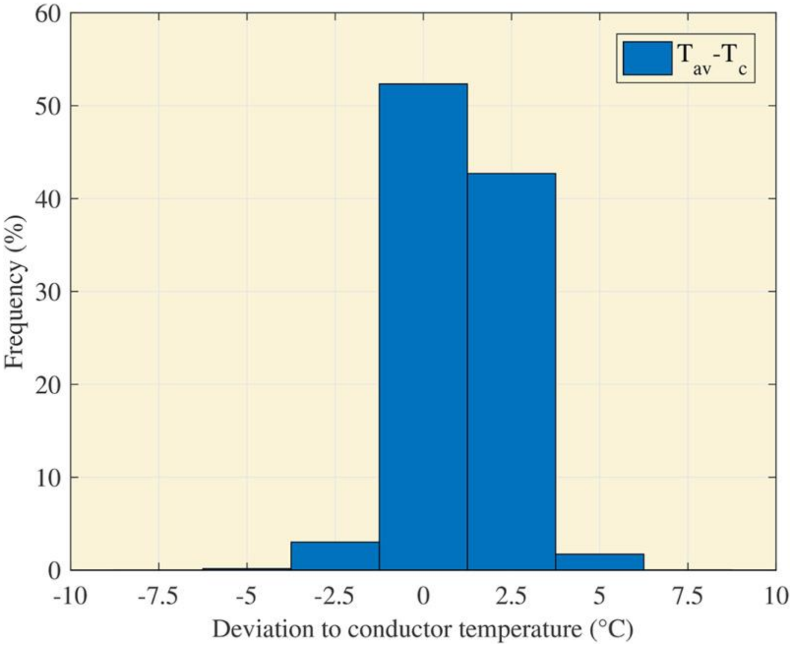
Results:

- the **average of the distributed temperature and the spot temperature measured** nearby the weather station are very similar, with the main difference in the smoothness of the temperature profile and **with variations lower than±5°C in more than 99% of the cases.**
- Even in the cases with the highest conductor temperatures the differences between the spot and average temperature are inside ±5°C.
- This is an important conclusion in favor of the **discrete temperature measurements to be extrapolated as the average vane temperature to calculate sag elongations.**



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Results:

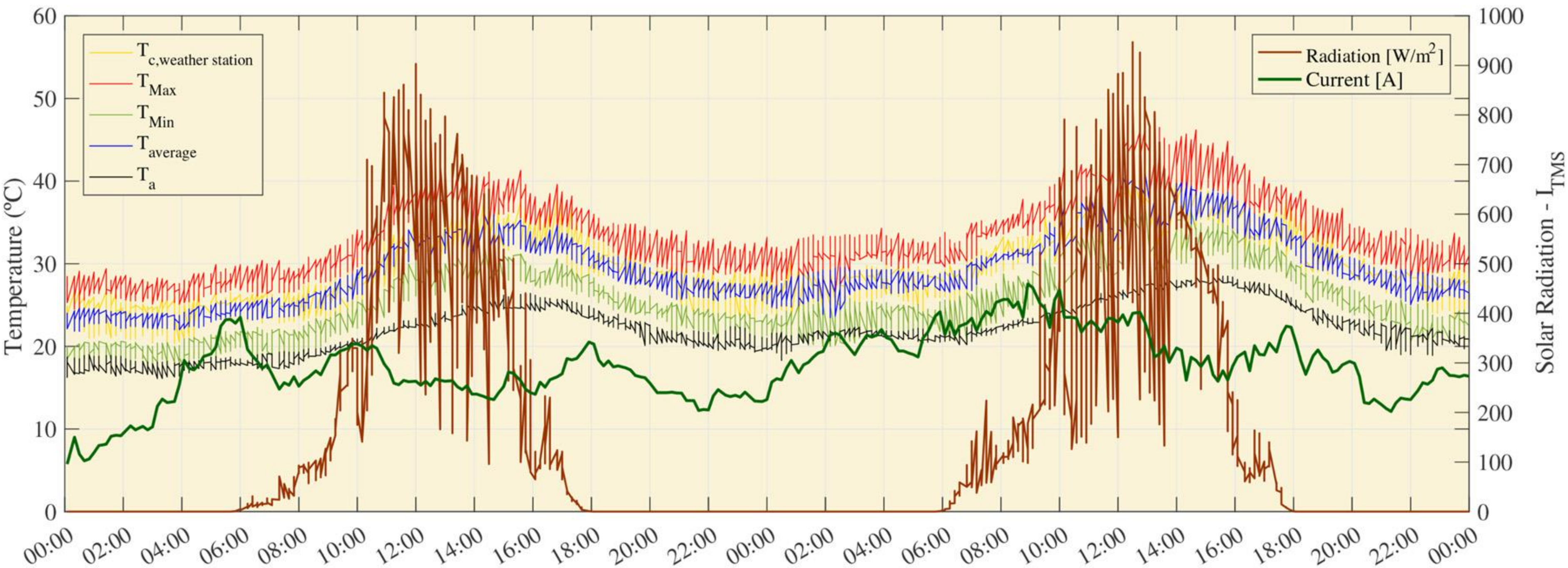
- Table shows the **average of the standard deviation** of T_c, T_{av}, T_{max} and T_{min} for the 6 areas of influence, i.e., in every recorded sample the standard deviation between the values of the measures of the six areas of influence is calculated and then the average of the standard deviation for all the recorded samples is summarized.

Average of the standard deviation between areas of influence.

Temperature measurement	Standard deviation
T_c (spot temperature)	1.6
T_{av} (average temperature of the area of influence)	1.2
$T_{\max}$ (average temperature of the area of influence)	1.7
$T_{\min}$ (average temperature of the area of influence)	1.2

Results:

- As a matter of **example** a specific day is represented with the values of the spot temperature, the average, minimum and maximum distributed temperatures for the corresponding area of influence. Furthermore, solar radiation, ambient temperature and current are also represented.



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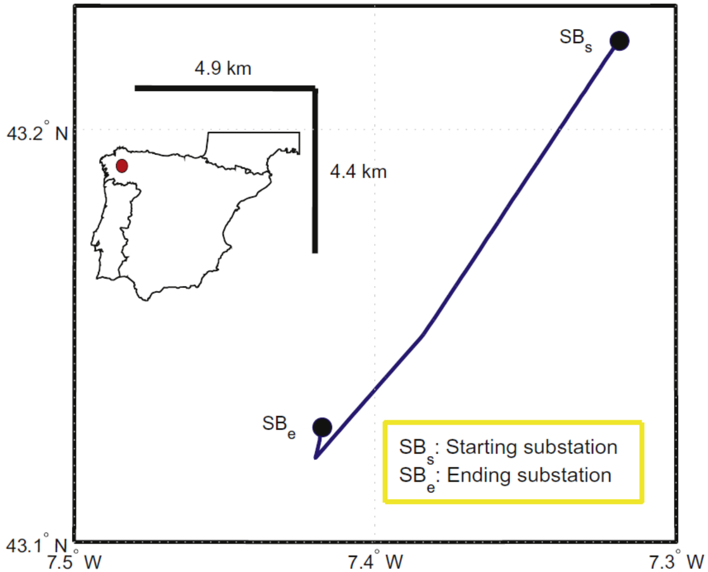
Case of study:

- To study the advantages of operating an overhead line under static and dynamic rates, **the electrical** (U_g; I; S_g; P_g; Q_g and cos φ) **and environmental** (u_h; φ_h; I_b; T_a and T_c) **real-time data were averaged every 4 min for an entire year** (from January 2015 to December 2015).
- **132-kV** overhead line with an **LA-110-type conductor** in northern Spain. The distance between the starting and ending substations is **L = 14.768 km**.



Technical data of the measuring equipment.

Measurement	Measuring equipment
Conductor Temperature (T_c)	TMS. 0–120 °C
Conductor current (I)	PQA. 1–5·CT_{Ratio} A ±0.1%
Conductor voltage (U_g)	PQA. 0–900·PT_{Ratio} V ±0.1%
Active power (P_g)	PQA. ±5 kW·CT_{Ratio}·PT_{Ratio} ±0.2%
Reactive power (Q_g)	PQA. ±5kVar·CT_{Ratio}·PT_{Ratio} ±0.2%
Apparent power (S_g)	PQA. ±5 kW·CT_{Ratio}·PT_{Ratio} ±0.2%
CT_{Ratio} and PT_{Ratio}	800/5 A and 132,000/110 V
Frequency (f_g)	PQA. 42.5–62 Hz ±5 mHz
Solar Radiation (I_b)	Pyranometer. 0–1100 W/m^2 ±0.5%
Wind Speed (u_h)	Anemometer. 0–60 m/s ±0.3 m/s
Wind Angle Direction (φ_h)	Anemometer. 0–360° ±2°
Ambient Temperature (T_a)	Thermometer. (−20)–80 °C ±0.3 °C

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Results:

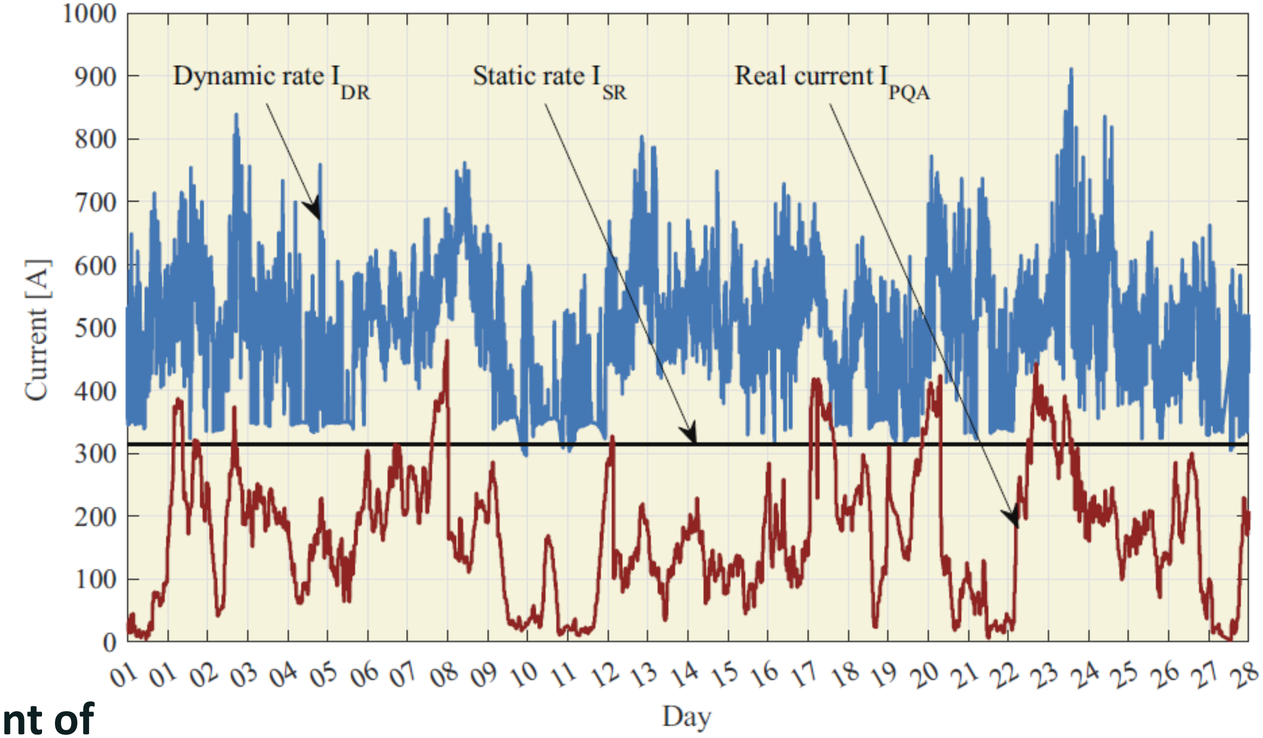
- The data recorded in 2015 for the described line were analysed, and the **real current I_{PQA}** was **compared with a static I_{SR} and a dynamic I_{DR} rating operation** during the same period. The studied **line** was **not heavily loaded**, and thus**, the actual operation was above the static rate for only short periods of time.**
- Table shows and compares the results of the three cases of real current I_{PQA}, static rating operation I_{SR} and dynamic rating operation I_{DR} during the entire year. For each case, **the annual generated, lost and useful energies were calculated.**

Annual generated, lost and useful energy for each case.

Case	$E_{g,tot}$ GW h	$E_{z,tot}$ GW h	$E_{u,tot}$ GW h	% losses
$A_{(\bar{I}=\bar{I}_{PQA})}$	231.5	2.4	229.1	1.1
$B_{(\bar{I}=\bar{I}_{SR})}$	545.1	9.9	535.2	1.8
$C_{(\bar{I}=\bar{I}_{DR})}$	834.7	23.6	811.1	2.8

Results:

- As an **example**, the real current I_{PQA} (red line), static rate I_{SR} (black line) and dynamic rate I_{DR} (blue line) are plotted for the month of February 2015.
- The load was higher than the static rate for only few hours during the month, but the current could have been significantly increased if it had been constantly operated. This result did not occur because of the low demand in the studied line.



Results:

- When the real case (I_{PQA}) is studied in detail for an entire year, we observe that **for 424 h, the line was operated over the static rate**, and **3.89 GWh of extra energy was evacuated** from the connected wind farms.
- Considering the relation of 290 tonnes of CO_2 emission by GWh of fossil fuel electricity production, this extra energy **led to 1,129.5 tonnes of CO_2 conservation in 2015.**
- Assuming that the 2015 averaged energy price was 62.24 €/MWh, this value indicates **242,402 € of extra income due to the dynamic rating** operation.

Results of real and dynamic rating operations vs. the static rate.

	Real case $\bar{I}_{PQA}$ vs. $\bar{I}_{SR}$	Dynamic rate $\bar{I}_{DR}$ vs. $\bar{I}_{SR}$
$H_{over\,SR}$ [h]	424	8385
$E_{over\,SR}$ [GW h]	3.89	257.8
M_{CO_2} [t]	1129	80,000
$€_{income}$	242,402	17,169,761

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More info:

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Distributed vs. spot temperature measurements in dynamic rating of overhead power lines

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Research Paper

CO_2 footprint reduction and efficiency increase using the dynamic rate in overhead power lines connected to wind farms

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Thank you very much

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