OPTIMIZATION OF TRANSMISSION LINE RATING IN RENEWABLE-HEAVY SYSTEMS

OPTIMIZAREA CAPACITĂȚII DE TRANSPORT A LINIILOR ELECTRICE ÎN REȚELELE CU PONDERE RIDICATĂ A ENERGIEI REGENERABILE

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Abstract: *As electricity demand continues to grow and more renewable energy is connected to the grid, making better use of existing transmission infrastructure has become increasingly important. Dynamic Line Rating (DLR) offers a practical solution by adjusting the capacity of overhead lines in real time, based on actual weather conditions, instead of relying on fixed limits. This paper evaluates the implementation of DLR in the Romanian power grid, focusing on its impact on line capacity, congestion, and overall system performance. The analysis shows that, under favorable conditions, DLR can safely increase the amount of power transmitted, improving efficiency and supporting the integration of renewable energy. At the same time, the study highlights challenges such as data reliability and regulatory considerations, suggesting that while DLR is promising, further development is needed for wider adoption.*

Keywords: Dynamic Line Rating (DLR), renewable energy integration, power system optimization, real-time monitoring, wind speed and direction, transmission capacity enhancement, Romanian power grid.

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Rezumat: *Pe măsură ce cererea de energie electrică continuă să crească și se integrează tot mai multă energie din surse regenerabile în rețea, utilizarea mai eficientă a infrastructurii de transport existente a devenit din ce în ce mai importantă. Tehnologia de Evaluare Dinamică a Liniei (Dynamic Line Rating - DLR) oferă o soluție practică prin ajustarea în timp real a capacității liniilor electrice aeriene, pe baza condițiilor meteorologice reale, în loc să utilizeze limite fixe. Prezentul studiu evaluează implementarea tehnologiei DLR în rețeaua electrică din România, concentrându-se asupra impactului acesteia asupra capacității liniilor, a congestiei și a performanței generale a sistemului. Analiza arată că, în condiții favorabile, DLR poate crește în siguranță cantitatea de energie electrică transmisă, îmbunătățind eficiența și sprijinind integrarea energiei regenerabile. În același timp, studiul evidențiază provocări precum fiabilitatea datelor și aspecte de legislație, sugerând că, deși DLR este o tehnologie promițătoare, este necesară o dezvoltare suplimentară pentru o adoptare mai largă.*

Cuvinte cheie: Dynamic Line Rating (DLR), integrarea surselor regenerabile de energie, optimizarea rețelei electrice, monitorizarea în timp real, viteza și direcția vântului, creșterea capacității de transport, rețeaua electrică din România.

1. Introduction

Due to the increasingly rapid growth of renewable energy resources, as well as political and legislative contexts around the world, power systems development plans have become a heated debate nowadays and the need to become energetically independent is far greater than a few years ago. The drawback is that the grid has to be prepared for all improvements, but if one looks closer will find out that in most cases, several investments need to be done so that the grid will be capable of handling the changes. One promising solution in this context is Dynamic Line Rating (DLR), a technique that determines the real-time ampacity of overhead transmission lines based on actual environmental conditions rather than static assumptions. The purpose of this paper is to assess the results of implementing Dynamic Line Rating in the Romanian power grid. The study aims to evaluate the impact of DLR on transmission capacity, congestion management, and overall system performance, while also identifying the challenges and opportunities associated with its implementation in the national power grid.

2. Concept of Dynamic Line Rating (DLR)

I. General description

One of the most challenging topics is increasing the current of the line, in other words the ampacity of the conductor. It is known that all lines have a certain limit when it comes to the current these can carry, otherwise problems concerning sagging, insulation and safety might come up. Usually, these limits are "static" meaning that they do not vary with weather conditions, but it is proved that it is not true. [1]

This is where the "Dynamic Line Rating" comes into light, as this concept refers to a grid-enhancing technology that calculates the real-time ampacity of overhead transmission lines based on weather conditions [2]. Several environmental and physical factors influence the dynamic rating of a transmission line. Ambient temperature plays a critical role, as higher temperatures reduce the conductor's ability to dissipate heat. Wind speed and direction are among the most significant factors, as they greatly aid with convective cooling; even moderate wind can substantially increase line capacity. Solar radiation contributes to conductor heating, particularly during clear daytime conditions. Additionally, the physical characteristics of the conductor, such as its material, diameter, and surface properties, affect heat transfer. Figure 1 explains how the static approach is not as efficient as DLR.

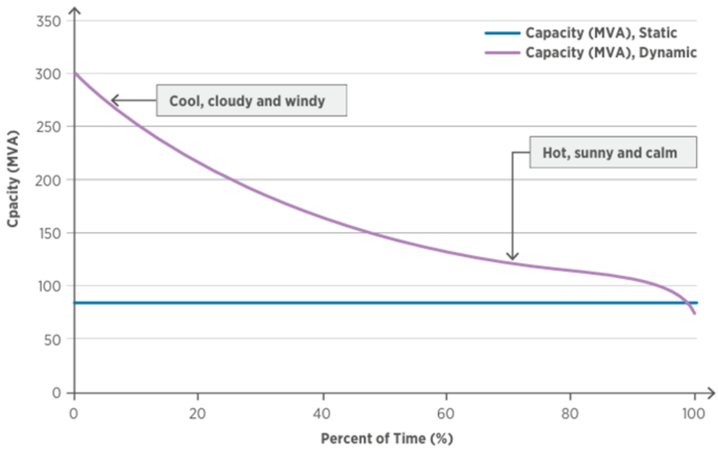

Fig. 1. Comparison of static and dynamic current limit [3]

In figure 2, depending on different factors, the impact of DLR is presented.

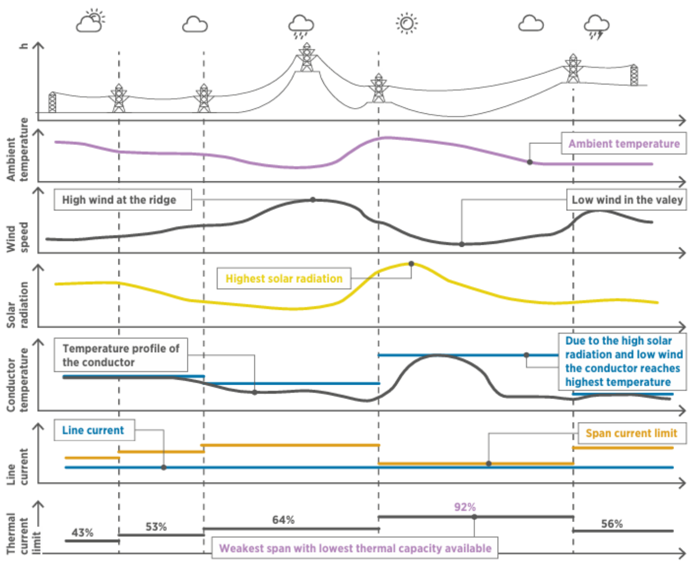

Fig. 2. The variability of influencing factors on DLR [3]

II. Advantages of using DLR

The main advantages of using DLR rather than the static approach are listed below:

a) Old infrastructure: by providing dynamic ampacity values, DLR helps operators to tackle line loading more efficiently than with fixed seasonal values. Even though DLR does not guarantee increased lifespan of a conductor, it handles the risk of thermal overload due to static limits [4].

b) Cost efficiency and grid optimization: DLR allows existing lines to carry more power when conditions are good, reducing the need to build new lines and lowering costs and environmental impact [5].

c) Climate resilience: DLR helps power systems adjust to changing weather, making infrastructure more robust against the effects of climate change [5].

III. Types of DLR

There are two types of DLR: Ambient-Adjusted (DLR-AA) and Real-Time Monitoring (DLR-RTM). The difference lies in the fact that one uses just temperature and the other uses both temperature and wind speed across the line [1]. AA-DLR collects maximum temperature data and uses it to estimate how much power the conductors can carry. The data is taken either hourly or daily, depending on the grid operator. However, it assumes wind speed remains constant, which makes it less accurate. DLR-RTM, on the other hand, are using meteorological stations mounted on the support towers of overhead lines and environmental data is collected and used to continuously update the ampacity of the conductor in real time.

IV. Projects developed in Europe

DLR projects have been already tested in other countries around the world and there is also an ongoing project in Romania. For instance, the transmission system operator Elia (Brussels, Belgium) introduced a mechanical monitoring system as part of a research project carried out with the University of Liège in 2008. Two years later, in 2010, a similar approach was implemented by RTE, the French transmission system operator, on lines rated at 150 kV, 245 kV, and 400 kV.

In Hungary, researchers from the Budapest University of Technology and Economics launched an innovative DLR pilot using GridGuard platform. Their system integrates distributed physical sensors with AI-based algorithms to identify critical timestamps and implements virtual sensors where they are most needed, further demonstrating the potential of DLR to improve real-time grid management [6].

3. Theoretical aspects

he purpose of this paper is to present an overview of how DLR technology impacts the Romanian transmission system, especially in the south-east region, which has a high concentration of wind and solar power plants and a growing number of energy storage systems.

As mentioned before, the ampacity refers to the maximum value of the current that can be transported by an electrical line under safe conditions and without losing the natural properties of the material. The most restrictive element of the ampacity is represented by heat generated through Joule effect and solar radiation. DLR has come to the attention of many researchers and advantages of using this technology emerged. Such examples of studies can be depicted in [7], [8], [9] and [10].

The IEEE standard [11] offers the guideline for calculation of the heat equilibrium for a conductor using equation (1).

$$Q_a + Q_s = Q_c + Q_r \quad \left[\frac{W}{m}\right] \tag{1}$$

with: Q_a – heat generated by the flow of current through a conductor, Q_s is the heat obtained from the solar radiation, Q_c – heat lost due to convection and Q_r – heat lost due to radiation.

The maximum current can be extracted, as presented in equation (2).

$$I_{max} = \sqrt{\frac{Q_r + Q_{nc} - Q_s}{R(t_c)}} \quad (2)$$

All data are estimations of the Romanian power system and no certain measurements were conducted in order to determine the values.

4. Case study

In order to present the impact of using Dynamic Line Rating method on the Romanian power system, NEPLAN was used and the south-eastern part of the transmission system was modelled. This region is known for its abundant renewable energy generators, as most of the wind and solar power plants are installed there.

This case study proposes an analysis of the variation of the maximum admissible current as a function of atmospheric parameters, such as: ambient temperature (for example, in Romania this varies from -25°C to 45°C from winter to summer), wind speed (the most important parameter, given the study's focus on energy generation from wind farms), solar radiation, etc.

As for the types of conductors used, the 400 kV network will use two conductors with a cross-sectional area of 450 mm², while the 220 kV network will use a single conductor with a cross-sectional area of 450 mm². The input parameters used in the calculation are:

- R_{20} = 0.00008 Ω/m (for 220 kV line) / R_{20} = 0.00004 Ω/m (for 400 kV line);
- α = 0.00403 1/ºC;
- D = 0.028 m;
- ε = 0.5;
- T_c = 70 ºC;
- T_a = air temperature;
- v = wind speed;
- S = solar radiation intensity.

The analysis shall focus on the dependency of the maximum admissible current and maximum admissible active power that can be transferred by the transmission lines (220 kV and 400 kV) in summer off-peak, hour 11:30, T_a = 35 ºC, S = 900 W/m2. One other important note is that the off-peak during summer occurs around noon due to the increasingly impact of prosumers on the transmission grid.

Table 1 and table 2 describe the variation in the rated current and maximum power on 220 kV and 400 kV lines across different load profiles. The active power values reported in the study were derived from the calculated admissible conductor current assuming a three-phase system operating at the nominal line-to-line voltage of 220 kV, respectively 400 kV, and a unity power factor. It should be emphasized that this value represents the active power associated with the considered conductor thermal limit and should not be interpreted as the overall maximum transfer capability of the transmission line or power system. The latter may be further constrained by other equipment ratings, voltage limits, stability criteria, and system-security requirements.

Table 1. **Variation in the rated current and maximum power on the 220 kV line across different load profiles**

	v [m/s]	5	10	15	20
Summer		off-peak; 11:30; 35 ºC			
	I_{adm} [A]	624	776	880	962
	P [MW]	238	296	335	367

Figures 3 and 4 present the variation of the ampacity and the active power that can be transported on a conductor used at a voltage of 220 kV depending on wind speed.

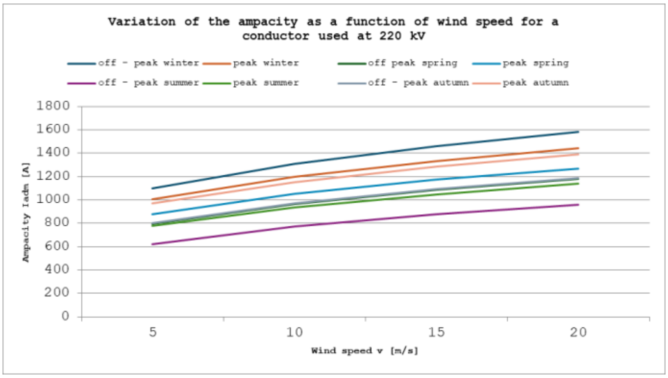

Fig. 3. Variation of the ampacity as a function of wind speed for a conductor used at voltage of 220 kV

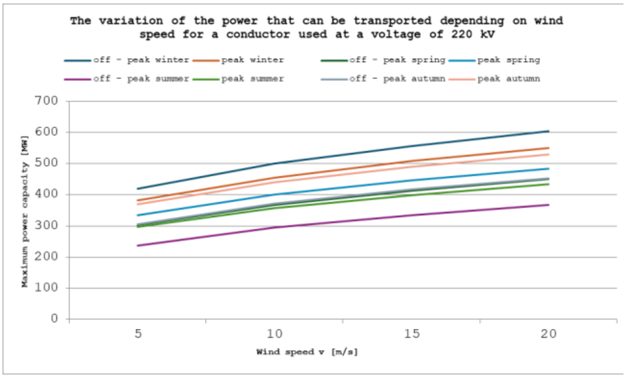

Fig. 4. Variation of transported power depending on wind speed for a conductor used at voltage of 220 kV

Table 2. **Variation in the rated current and maximum power on the 400 kV line across different load profiles**

	v [m/s]	5	10	15	20
		off-peak; 11:30; 35 °C			
Summer	Iadm [A]	883	1097	1244	1361
	P [MW]	612	760	862	943

Figures 5 and 6 present the variation of the ampacity and the active power that can be transported on a conductor used at a voltage of 400 kV depending on wind speed.

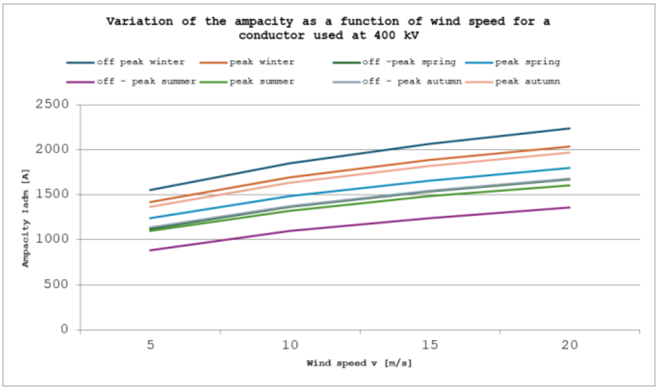

Fig. 5. Variation of the ampacity as a function of wind speed for a conductor used at voltage of 400 kV

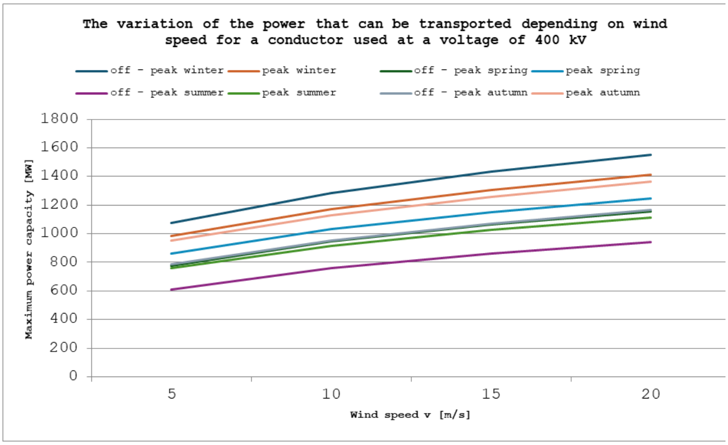

Fig. 6. Variation of transported power depending on wind speed for a conductor used at voltage of 400 kV

The TEST power grid modelled in Neplan is presented in figure 7, consisting of ten 220 kV lines and twenty 400 kV lines with five 400/200 kV transformers. Out of the eleven generators, only five are classic thermoelectric and the remaining six are wind power plants. In table 3, table 4 and table 5, there are presented the characteristics of the generators, the loads and the lines' parameters.

Table 3. **Generators**

Gen.	P [MW]	Production Type
G1	300	Thermoelectric Power Plant
G2	290	Thermoelectric Power Plant
G4	290	Thermoelectric Power Plant
G6	300	Thermoelectric Power Plant
G5	132	Wind Power Plant
G9	310	Wind Power Plant
G7	41	Wind Power Plant
G8	290	Wind Power Plant
G10	360	Wind Power Plant
G3	150	Thermoelectric Power Plant
G11	300	Wind Power Plant

Table 4. **Loads**

Load	**Substation**	**Off - peak summer**	
		[MW]	**[MVAr]**
L-461	S8	59	6
L-749	S15	17	6
L-751	S9	45	14
L-753	S1	163	56
L-755	S7	88	13
L-759	S14	73	25
L-761	S16	38	13
L-765	S17	36	8
L-767	S18	22	10
L-769	S11	38	13
L-840	S10	18	6

Table 5. **Lines' parameters**

Line	L23	L12	L14	L93	L58	L15	L56-3	L56-2	L67	L710	L310-1	L1112	L711	L1314	L1213
L [km]	55	64	37	29	73	21	23	23	71	34	43	7	29	86	90
Line	L1014	L1516	L515	L1617-2	L1718-1	L1718-2	L1617-1	L420	L1819	L730	L725	L1151	L1814	L1141	L177
L [km]	85	119	38	25	67	67	25	34	64	74,8	49,5	30	84	93	40

Per unit parameters of overhead electric lines are presented in Table 6.

Table 6. **Per unit lines' parameters**

Line	R [ohm/km]	X [ohm/km]	B [S/km]
220 kV	0,034	0,32	3,6
400 kV	0,068	0,41	2,7

For the simulation in the TEST grid, the limiting case of transmission capacity that shall be used is the summer season, when high temperatures create conditions that are unfavorable for increasing capacity.

Given that the rated power of wind farms is reached at a wind speed of 15 m/s, this speed will be used when calculating the maximum transmission capacity during power generation in wind power plants (WPP). The current limit for 400 kV lines is 1000 A, and for 220 kV lines, the limit is 700 A.

The simulation was conducted on a summer off-peak profile. Summer is characterized by high temperatures, which negatively impact the capacity of the power lines.

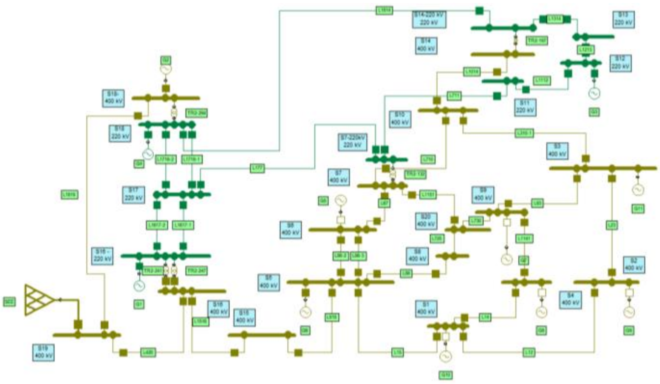

Fig. 7. The TEST power grid used for testing the DLR technology

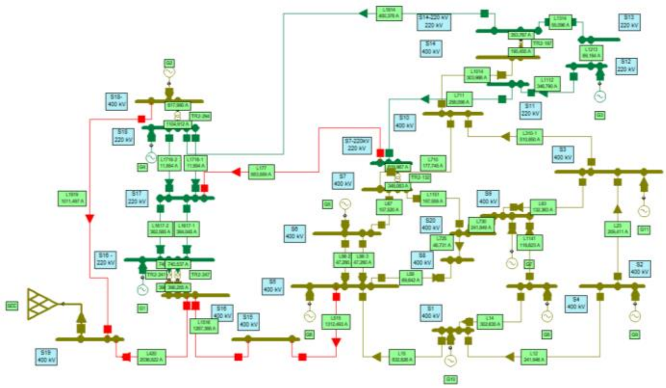

Fig. 8. Summer off-peak with all WPPs

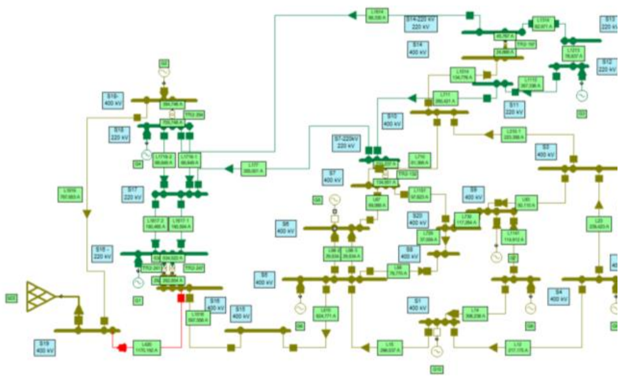

Fig. 9. Summer off-peak without WPPs 5, 10 and 11

This scenario is characterized by a significant decrease in consumption due to the contribution of prosumers. As shown in figure 8, several transmission lines exceed their admissible current limits in the load flow calculation. In this case, the current reaches 2037 A for the 400 kV lines and 854 A for the 220 kV lines. These values exceed the corresponding dynamic ampacity limits of 1244 A and 880 A, respectively.

Although the dynamic ampacity values remain above the static ratings considered in the study, their magnitude is adversely affected by the summer off-peak operating conditions. In particular, this period occurs around midday, when solar radiation and ambient temperature are relatively high. These conditions increase the conductor temperature and reduce the beneficial cooling effect provided by the wind. Therefore, the dynamic limits are lower than they would be under more favorable meteorological conditions, although they remain higher than the corresponding static ratings.

To ensure secure operation under the considered dynamic conditions, the active power production of the WPPs must consequently be curtailed. Thus, WPP 5, WPP 10, and WPP 11 are disconnected, as illustrated in figure 9. This way the DLR becomes capable of relieving the congestion.

5. Conclusions

The study aims to determine the variation in the maximum admissible current for the transmission grid, covering voltage levels of 400 kV and 220 kV. In both cases, it was found that the maximum admissible current varies depending on atmospheric parameters: wind speed, ambient temperature, solar radiation, pollution, etc. For example, for the 400 kV line, the admissible current varied between 880 A and 1360 A. This is a significant difference which demonstrates that the implementation of DLR would be highly necessary, especially for transmission grids that include wind power plants.

In the case of the TEST network, an attempt was made to replicate part of an ENTSO-E system to demonstrate its usefulness and provide results as close to reality as possible. The calculation was performed considering: wind speed, ambient temperature, solar radiation, and conductor type (a conductor with average aging) to obtain the most relevant results. To ensure the accuracy of the calculations, additional factors such as wind direction and flow patterns can be incorporated into the model.

Future developments of the proposed approach could focus on a more comprehensive integration of DLR into power system operation. The results show that DLR can provide additional thermal capacity and reduce unnecessary restrictions associated with conservative static ratings. However, the additional capacity cannot eliminate severe congestion when the actual power flow significantly exceeds the dynamic rating. Its effective utilization should therefore be considered together with system operating conditions and congestion-management measures.

Furthermore, future studies could consider the spatial variability of wind speed, wind direction, ambient temperature, and solar radiation along the transmission line route, as the most restrictive section of a line may determine its effective operational rating. Another relevant development would be the integration of DLR-based ratings into contingency analysis and N-1 security assessment, considering the redistribution of power flows following a contingency. These developments would provide a more comprehensive assessment of the practical applicability of DLR in transmission system operation.

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