CHALLENGES TO THE INTEGRATION OF DYNAMIC LINE RATING AND AMPACITY FORECAST IN REAL-LIFE OPERATION TO INCREASE USABLE NETWORK CAPACITY

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ABSTRACT

This proposed paper focuses on the criteria that need to be met to allow DSOs to effectively use Dynamic Line Ratings in real-life operations. Different pilot projects have proven that DLR technology works in the field, effectively increasing line capacity of existing overhead lines in a reliable way. Many papers highlight those results, but now the focus is shifting to how this technology can be put to best use: where it makes sense and how the results should be used to maximize the benefits while reducing operational risks. This paper highlights the experience system operators have had, and the different stages to complete in order to make an operational use of DLR technology: confidence in the technology, IT integration, adaptation of operational processes, and assets investment strategy.

The following specific aspects will be addressed:
Combining Active Network management and DLR. *Dynamic management of intermittent generation and load showed promising solutions regarding balancing. DLR can fit in to enhance flexibility, and solve congestion issues, by providing more line capacity when available. A better overall optimization can then be performed using DLR monitoring. Another benefit lies in the increase of connection capacity of existing networks by combining flexible connection with DLR.*

Day-ahead forecasting of DLR. *Most decisions regarding network operation, security calculations, and market are taken many hours/days in advance; therefore if DLR is to influence these decisions, a reliable forecast of the DLR values is required. Within the EU-funded Twenties project, the University of Liège, Belgium, has developed such a capability with the* Ampacimon *sensor. This unlocks value from DLR forecast, as it increases the flexibility of the network to solve congestion issues related to the increasing share of intermittent power from Renewable Energy Sources (RES) in the energy mix.*

In conclusion, integrated solutions involving DLR forecast and ANM, are emerging. They achieve the objective of increasing the efficiency of the existing network and help integrate intermittent renewable energy sources in a safe and economical way.

INTRODUCTION

Wind farms and PV development have continuously grown over the past years. In Europe only, wind farm installed capacity was 90GW in 2011 with more than 10% annual growth [1], while a PV growth from 30 GW in 2010 to 53 GW in 2011 has been reported [10]. This change in the production portfolio generates very significant needs for additional transport & distribution capacity at all levels of the network. It is more and more obvious that replacing, uprating and building the required new electrical power lines [2] will become the main bottleneck to reach the EU 20-20-20 objectives. In particular, for the distribution network, sufficient operational margins have always been ensured through the *fit and forget* approach [11]. But the preservation of such conservative margins comes at continuously increasing network reinforcement costs. Therefore it has become mandatory to develop new approaches to increase the efficiency of the existing network assets in a secure way and deliver the required capacity in a timely and economically viable way.

One of the solutions to adapt the system to these new constraints is Dynamic Line Rating (DLR), which allows TSOs and DSOs to monitor their existing assets in real-time and significantly increases the dynamic line capacity, also known as ampacity, over the traditionally used static/seasonal ratings of Overhead Lines (OHL). Underground cables could be operated with DLR as well, but as their thermal time constants if far greater than for OHL (hours vs. about 15 min.), they can be operated at a higher rating on a cyclic basis [6]. This paper thus only focuses on DLR applied to OHL.

Moreover, Dynamic Line Rating of overhead lines combined with Active Network Management (ANM) have proven to be very promising in this frame [3], as a strong positive correlation between wind farm generation and an increase of nearby OHL ampacity has been shown. Regarding wind farms, extra line capacity is thus available when required, and this without waiting for infrastructure reinforcements/extensions. The optimum efficiency is obtained when DLR is combined with the possibility to curtail generation and with the availability of flexible loads (electric heaters, boilers, electric car batteries, …) When DLR is used, allowing a small percentage of curtailment significantly increases the amount of renewable generation that can be connected to the existing network.

However, up to now, few experiments addressed ampacity forecasting, which is of prime interest for

TSOs, DSOs and the whole electricity market. Indeed most decisions regarding the operation of the network are days ahead, such as the capacity nominations for the day-ahead electricity market [5].
The University of Liège (ULg), Belgium, successfully developed an algorithm based on real-time DLR measurements and weather forecasts within the EU Twenties project to provide two-day ahead ampacity forecasts with controllable prediction interval, despite high sensitivity of dynamic rating w.r.t. low wind speeds, typically hard to measure and forecast [4].

Hence, in addition to ANM strategies, DLR is definitely a flexibility tool to be considered in future distribution networks (DN). Moreover, short- and medium-term ampacity forecasts offer new operational possibilities in many scenarios. For example, exploiting flexible loads within an ANM scheme is challenging, as their modulation range is constrained. This would imply that after increasing the consumption of the flexible loads during a certain time period, the DSO would be constrained to later decrease their consumption, which may significantly aggravate congestion [7]. Involving DLR forecasts in that scheme could provide variable ampacity over that time horizon. Another optimisation could then be achieved and release the congestion.

This paper deals with the needs to be met for large deployment of DLR in today's transmission networks and how DSOs can benefit from TSOs' experience to include DLR in future operational planning.

CONDITIONS TO BE MET FOR LARGE DEPLOYMENT OF DLR TECHNOLOGY

Today, DLR has become a robust and reliable technology. However, needs must be fulfilled for large deployment of the technology. They are investigated below.

First, System Operators (SO) need to believe in the technology. That's the reason why many pilot installations have been driven with successful outcomes these last years. This point can be considered overcome today with collaborating TSOs.

Second, TSOs have to ensure a smooth and global integration of this technology in their IT system, including DLR data in network security analyses (e.g. N-1 situations), and keeping the information up-to-date continuously. DSOs not having such constraints as the TSOs, could rely on day-ahead ampacity forecasts for operational planning, with limited central monitoring in real-time, coupled with use of alerts and automatic protection relays. In this regard, it should be noted that communication systems has become a major concern for smart grids technologies reliability. In the case of communication failures, safe fallback modes have to be well thought up beforehand, to be able to maintain the system's security until complete restoration.

Third, new processes have to be defined to adapt system operation to DLR. But highly regulated entities like SOs follow very strict operating rules and processes. A large-scale deployment of DLR brings a lot of information, which has to be gathered, processed, and managed to come up with decision rules to apply on the field in due time. However, those processes may vary, depending on the availability of control tools, the particular topology and regulation rules. DSOs have to define the most efficient way to deal with this new piece of information and bring it in line with operator's procedures: how to manage/implement real-time measurements ?, how to deal with TSO and consumers?, how to deal with alerts?

Fourth, DLR investment and operational costs must be balanced with other available smart grids or conventional solutions, taking into account implementation lead time, return of investment (ROI), reliability, added flexibility, available manpower, investment prioritisation, as well as the regulatory framework. Some uncertainties, and the lack of preceding experience may push utilities to unfortunately opt for unsuited and expensive, but more familiar options. On top of that, a clear methodology has to be developed to assess the ROI, or avoided costs, provided by DLR, as investors need a clear visibility on their investments.

PROPOSED SOLUTIONS AND IN-THE-FIELD RESULTS

Confidence in the developed technology has been built over the last six years with collaborating TSOs. Remarkable reliability of the real-time measurements (±20cm) and significant gain on monitored lines, resulted from close cooperation between the product development team and TSOs (Fig. 1 and 2). Today, the tested DLR system can be installed on conductors roughly from 12 mm to 50 mm in diameter, but a smaller version of the sensor is being developed.

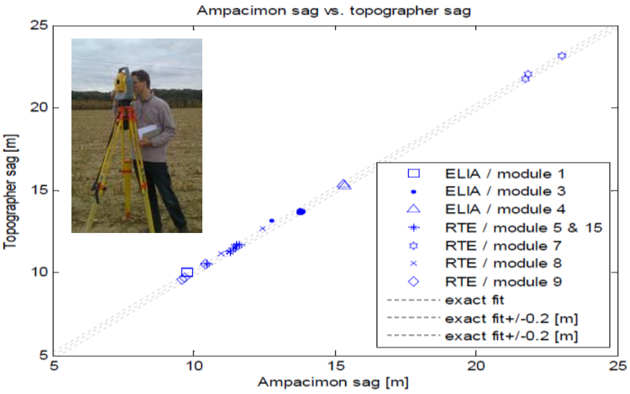

***Fig. 1**: Studied DLR's sag measurement vs. independent sag topography measurement showed very good agreement (±20cm).*

Regarding TSO's IT system integration, a full stand-alone data processing and communication software has been developed. Data is sent in real-time to the Energy Management System (EMS), through their SCADA (TASE.2 protocol), so that it may be used dynamically for network security calculations (PAS software). A full front-end web-based display has been implemented as well. Safe fallback modes have been implemented, yielding a conservative value for ampacity in case of data inconsistency or communication failure.
IT operational implementation and integration in TSO's EMS is today up and running, and is used in operation (real-time and 1h-4h forecast) for the 150kV Bruges-Slijkens line experiment in Belgium. Less congestion alerts on the equipped line have been reported since by ELIA, the Belgian TSO. The overall benefits (spared actions, redispatching cost, …) has still to be assessed.

Today, those two required stages experience different degrees of completion depending on the DLR system involved.

For DSOs, DLR measurement principle remains the same, therefore the same accuracy and reliability can be achieved for DN. Regarding IT implementation, day-ahead forecast can be readily manageable, while possibly decentralised real-time monitoring may be coupled with protection relays featuring DLR protection. Incidentally, some relays dedicated to DLR are already available on the market. But they only feature basic weather-based ampacity. Clearance monitoring provided by in-line sensors guarantees safety and security. Smooth integration of DLR could be achieved through those dedicated relays.

Regarding processes, even though some line check-up procedures prior to DLR installation have begun to appear [9], fully adapted operational processes need more experience in-the-field, in particular through the use of forecasts.
In fact, short-term ampacity forecast (>15min) is required to know the forthcoming dynamic rating, so that appropriate resources be allocated in case of contingency. Similarly, if the DSO has ANM tools available (*e.g.* generation curtailment and flexible loads), a short-term ampacity forecast is required to optimise the short-term decision-making process. A forecast algorithm using DLR measurement history has been developed for TSOs, and can be reused for DN applications (Fig. 3).

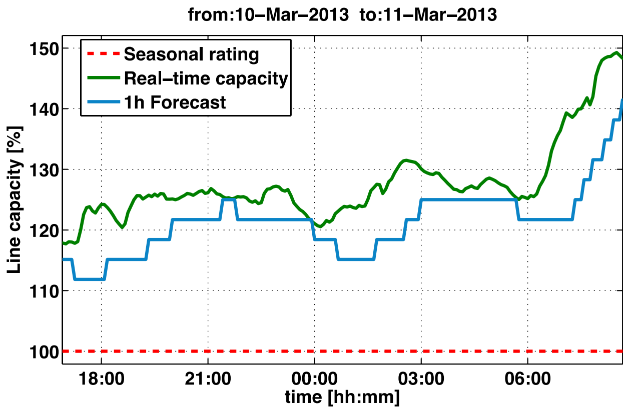

Fig. 3*: Actual DLR and the corresponding one hour ahead forecast, over 12 hours. DLR short-term forecast can be used in the decision-making process, for optimising line usage.*

However, even if intraday market is developing, it suffers low liquidity [5], and it is today still confined to adjusting day-ahead nominations. In fact, DLR essentially gets its added value when it can safely forecast line ratings one day ahead, because most of the market transactions are performed at this time horizon, before gate closure. Anticipation is the key, as it provides more lead time in the overall decision-making process, which gives access to safer and more optimal solutions, thus preventing incidents and congestions, at a minimal cost.
A forecast algorithm has been successfully developed for the Netflex Demo within the EU TWENTIES Project (2010-2013), providing an average capacity improvement of more than 10% over static rating with 98% confidence, on two 150kV lines (Fig.4).

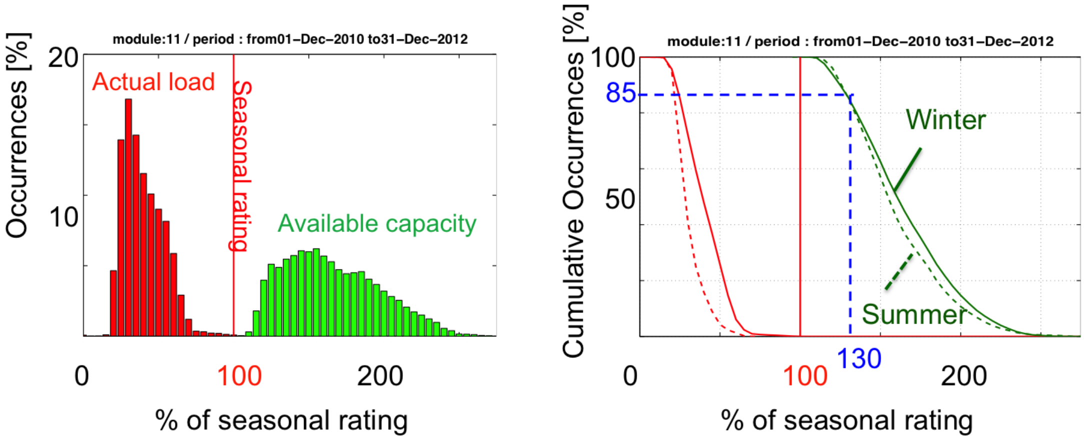

Fig. 2*. Left: typical histogram of power line loading. Actual load (under normal operating conditions) and ampacity. Right: corresponding cumulative histogram, with winter/summer load. More than 130% of the seasonal rating is available 85% of the time.*

This is a major goal achievement, as thisprovide a significant added value to DLR, which can now be used as a market tool, and in day-ahead security calculations.
In addition to real-time monitoring and short-term forecast, operational experience of that medium-term ampacity forecast is being built by ELIA, which has confirmed its interest in the technology by the forthcoming installation of that DLR system on 6 new lines in its network.

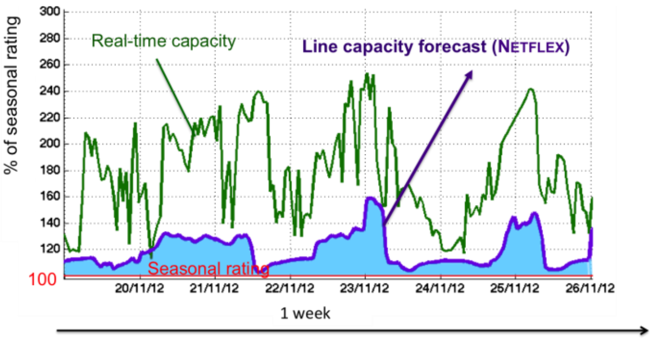

Fig. 4 : (i) real-time capacity (=ampacity) and (ii) Twenties two-day ahead forecast, developed at the University of Liège, Belgium, guarantees a safe ampacity forecast.

The goal of NETFLEX was to demonstrate that network flexibility enables getting more transmission capacity where and when it is needed without compromising operational security, and safeguarding security of supply. Only a few percent increase on critical lines already bring significant gain for the market. Distribution networks could directly benefit from day-ahead ampacity forecasts results, as the forecasting process is actually the same.

Moreover, prediction interval can be controlled with that medium-term forecast algorithm. If the DSO is to control its network in real-time, as it is the case for the TSO today, then several optimisation scenarios combining ANM and DLR can be performed in day-ahead, with various prediction intervals for DLR forecasts. Forecast uncertainty could explicitly be taken into account in the optimisation problem. Indeed, higher gain with lower prediction interval on ampacity forecast could be proposed, provided control means are available in real-time, to make up for an incorrect forecast.

On the planning side, future interaction models between all stakeholders (DSOs, TSO, producers, providers, aggregators, investors,…) are still being studied today, as evidenced by the GREDOR Project, funded by the Walloon Region (2013-2017), Belgium. Present penetration of renewable energy sources (RES) and distributed generation (DG) is likely to continue. RES growth leads to congestion issues when, within the distribution network, high generation and low consumption arise simultaneously. DSOs may be offered public or private incentives, possibly by wind farm investors, to accommodate additional RES connections, or even be compelled to it, otherwise suffering financial penalties. In this frame, massive investment for preserving conservative margins can only be done at a prohibitive cost. DLR can then be a valuable investment, as it could dramatically reduce congestion management costs, by only using monitoring of existing assets. Hence, DLR also allows delay of capital expenditure.
Another interesting combination with DLR is worth mentioning. Indeed, a strong positive correlation between wind farm generation and an increase of nearby OHL ampacity has been shown (Fig. 5). It can be physically explained by the fact that wind blowing on a wind farm also blows on OHL located in the vicinity. As the line is better cooled down, its thermal rating is increased. That correlation between wind farm generation and increase in line ratings would allow less curtailment of existing wind farms and/or more wind power connection using existing assets.

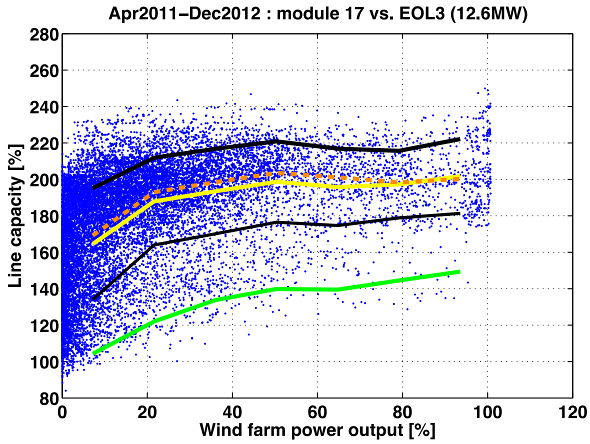

***Fig. 5** : Ampacity for one span of the power line causing the bottleneck versus wind farm generation for the Brugge-Slijkens line, located about 10km away from the wind farm. Mean (yellow) +/- 1 standard deviation (black), and percentile 50 (dotted orange) are given; percentile 98 (green) of this sample is provided for information purpose.*

Connection of DG in a short time as possible is no longer planned well in advance, and lines connected to it may be below the ideal capacity. Pressure applied to engineers to increase the allowable rating of lines often results in rapid decisions without in-depth analysis [8]. DLR can then fit in to provide more flexibility. Moreover, DLR systems allow to relocate monitoring, at low cost and rapidly, --- it can be fully operational in a matter of months ---, in contrast with other methods. For that matter, DLR seems indeed to be the best option for a network that is subject to power trading and high volatility of power flows, as it allows large dynamic capacity increases for short periods of time [8].

TSOs we have worked with are already carrying out a deeper reflection to encompass DLR in operational and planning processes. DLR installation criteria based on line overload level as well as weather statistics are being studied by ELIA. Discussions are also ongoing with

RTE, the French TSO, to equip a cross-border line with DLR, to improve global welfare by providing more line capacity to the market with existing assets. Undoubtedly, the accumulated experience of DLR on transmission networks will directly benefit its integration in the distribution network. In this regard, the OPTIGRID project (2013-2015) supported by the Walloon Region, Belgium, aims at developing DLR monitoring below 70kV to help accelerate wind farm integration. It also aims at adding predictive maintenance capabilities, and fault detection.

CONCLUSION

The renewable generation growth, the evolution of the consumption pattern (for example electrical vehicles), and the changes in the electricity markets sector will raise several challenges in distribution systems in a near future. Without re-thinking the system, issues such as congestion and renewable power curtailment are likely to appear more often than today. To avoid prohibitive network reinforcement costs, one of the key aspects is to accommodate the variability of the renewable energy sources by adding more flexibility to the network.
In addition to Active Network Management strategies proposed as alternatives to the dominant doctrine of *fit and forget* approach in distribution networks, it turns out that the network infrastructure *itself* can be flexible as well, beside generation and load flexibility.

The aim of this paper was to explore the criteria that need to be met to allow network operators to effectively use Dynamic Line Ratings in real-life operations through monitoring and forecasting, and allow large deployment of this technology.

Four main stages have been identified at the TSO level. But the accumulated experience on transmission networks will undoubtedly directly benefit future integration of DLR in the distribution network.
<u>Stage 1 & 2</u>: Confidence in the technology as well as full IT integration are required. Those stages have been successfully achieved through our experiments and close cooperation with the DLR manufacturer and integrator, and with involved TSOs these last years.
<u>Stage 3 & 4</u>: Development of adapted processes related to DLR (for operation and installation) and the availability of a methodology to assess the relevant network configurations to be equipped.
Those stages are underway at the TSO level, we believe they will be stimulated by the practical return of investment (ROI) and the added flexibility generated by the medium-term ampacity forecast, which has been validated in the field and which is now being used in operation.

Day-ahead ampacity forecasts with high confidence, resulting from the EU-funded Twenties project, offer a powerful flexibility tool for all market actors, as nominations can thus be adapted before gate closure. Moreover, all flexible load-generation scenarios can benefit from those forecasts. As prediction intervals can be parameterised, different optimisation schemes can be performed depending on control means available in real-time, like ANM.

In this changing landscape, network planning must be adapted: future interaction models between different stakeholders and market actors are being studied today. DLR technology has proven its usability as a flexibility tool for transmission networks. Therefore, it should definitely be considered in future distribution networks as well, in the overall planning, market, and operation processes, as it will help accelerate RES integration, and facilitate the market. By increasing thermal rating, DLR can be artfully combined with ANM to operate the network safely at a minimal cost.

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BIBLIOGRAPHY

[1] ENTSO-E, 2012, *Statistical Yearbook 2011,* Secretariat of ENTSO-E, Berlin, Germany, 10.
[2] ENTSO-E, 2012, *10-Year Network Development Plan 2012,* ENTSO-E AISBL, Brussels, Belgium, 62.
[3] P.Schell, J.-L. Lilien, H.-M. Nguyen and al., 2012, "Large penetration of distributed productions: dynamic line rating and flexible generation, a must regarding investment strategy and network reliability", *CIRED Workshop. Lisbon*, IET, paper 280.
[4] H.-M. Nguyen, B. Godard, P. Schell, J-L Lilien, 2013, "Reinforcement learning using weather forecast and power line sensor as a key to optimize your power line assets in a changing world for DSOs and TSOs", CIGRE Symposium, Auckland, NZ, paper 345.
[5] De Vos, K., Driesen, J., May 2009, "Balancing management mechanisms for intermittent power sources A case study for wind power in Belgium.", *6th International Conference on the European Energy Market,* pages 1–6.
[6] Caramia, P., Carpinelli, G., Vitola, A.L., and Verde, P., 2002, "Cyclic and Emergency Rating Factors of Distribution Cables in Presence of Nonlinear Loads", 10th Int. Conf. on Harmonics and Quality of Power.
[7] Gemine, Q., Karangelos, E., Ernst, D., Cornélusse, B., 2013, "Active network management: planning under uncertainty for exploiting load modulation", Proceedings of the 2013 IREP Symposium - Bulk Power Systems Dynamics and Control – IX.
[8] R. Stephen. 2004, B2-201: "Description and evaluation of options relating to uprating of overhead transmission lines", Cigré Paris.
[9] R Puffer, M Schmale, B Rusek, and *al.* 2012, B2-106 "Area-wide dynamic line ratings based on weather measurements", Cigré Paris.
[10] EPIA, 2014, *Global market outlook for photovoltaics 2013-2017,* EPIA, Brussels, Belgium.
[11] J. A. P. Lopes, N. Hatziargyriou, and *al.*, 2007, "Integrating distributed generation into electric power systems: A review of drivers, challenges and opportunities," *Electric Power Systems Research*, vol. 77, no. 9, pp. 1189–1203.