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Integration of 2 days-ahead capacity forecast to manage Belgian energy imports

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SUMMARY

The decisions regarding network operations and Electricity Market are taken 2 days in advance; a reliable forecast of the dynamic rating allows a better use of the line while keeping the same security level. The increased capacity also has an impact on market coupling, hence the electricity price.

Due to multiple nuclear plant outages, Belgium relied on massive energy imports during the 2014-2015 winter. Elia (the Belgian TSO) decided to use real time Dynamic Line Rating on all critical cross-border lines with France and the Netherlands. Elia deployed 38 Ampacimon sensors on 8 cross-border lines. A second objective was to deploy two-days-ahead DLR-forecast software.

This paper presents the operational use of day-ahead forecasts of dynamic line rating to reduce the risk of electricity scarcity in Belgium by increasing imports.

Based on the Twenties project results[1] (NETFLEX Demo), Ampacimon developed an innovative 2 days ahead ampacity forecast method allowing to reach high level of confidence. The rationale is based on historical real-time measurements (sag and wind from online sensors) to adapt weather forecasts to local conditions. The forecast confidence can be adjusted to operational needs by adjusting the trade-off between forecast gain and confidence level.

The DLR forecasts are computed every 6 hours for the next 60 hours using weather forecasts provided by national weather services. The dynamic rating forecasts are fully integrated in TSO tools likes SCADA, N-1 security analysis, market capacity allocation.

This paper presents the results of the forecasts during the 2014-2015 winter. The gain resulting from the dynamic rating forecast is presented along with the confidence level of real-time dynamic rating.

[1] An EU funded project. http://www.twenties-project.eu

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This paper also presents the benefits for the Electricity Market and the added value of combining DLR with a flow-based market coupling mechanism.

Ten years ago, dynamic line rating was a research topic. Five years ago, pilot projects showed that dynamic line rating was a real benefit for optimizing network utilizations. Now, it becomes a standard tool for managing grid challenges like renewable integration and variable loop flows. Elia has gone a step further by using dynamic rating forecast for network operations and capacity allocation on the integrated, coupled Central West Europe (CWE) electricity market.

KEYWORDS

Transmission lines – Dynamic line rating – Thermal rating – Weather forecast – Ampacity – Smart grids – Sensors – Planning – Network - Market.

INTRODUCTION

The large renewable energy (REN) development that has flourished since several years creates important changes in the transmission and distribution networks. The flows are more volatile and intermittent which increases the need for capacity while reducing the line usage factor (MWh transmitted per MW of transmission/distribution capacity).

The strategy to build new lines or upgrades/reconductoring requires large investments and cannot be operational fast enough. In the last ten-year network development plan [1], ENTSO-E estimates that the European Transmission network requires an investment of 150 billion euros to support the ambitious European renewable energy scenario. 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.

Dynamic Line Rating (DLR) is one solution to increase the network efficiency. By monitoring their existing assets in real-time, TSOs and DSOs can significantly increase the line rating over traditional static/seasonal ratings. As recommended in CIGRE TB-498 [2], the dynamic rating should be determined by direct measurement methods measuring the actual sag of the critical spans. Using indirect methods such as weather stations or weather models is not accurate since it cannot guarantee clearance [6]. A safe operation of the grid cannot be guaranteed, even less so in day-ahead forecast mode.

In Central Western Europe, for several years, the integrated electricity market has become a reality. Prices are determined by the law of supply and demand. Each country can import and export its electricity to other countries in the CWE region. However, these flows are limited by cross-border capacities between countries. In Western Europe in 2012, congestions rents on interconnections reached 1.2 billion euro [8]. These congestion rents measure the cost of market uncoupling due to limited capacity. By using Dynamic Line Rating on cross-border lines, congestion and market uncoupling reduced.

Most decisions on the electricity market are taken two days ahead, defining the margins available on grid elements for cross-border exchanges between energy markets. Ampacimon developed an innovative two days ahead forecast rating method based on weather forecasts and historical measurements from on-line sensors. The goal of the forecast is not to minimize the error between the forecast and the actual rating but to reduce the over-estimation error while still maximizing the gain over static seasonal rating delivered by DLR, when allowed by weather conditions. The proposed method is designed so that the forecast is less or equal to the real-time rating during more than 98% of time (i.e. 98% of confidence).

This paper presents the operational use of such tools in the Belgian grid during the winter 2014-2015.

In 2014, the unplanned outages of several nuclear power plants in Belgium could cause a risk of shortage during the winter in case of severe weather conditions.
To limit this risk, Elia, the Belgian TSO decided to implement DLR on all critical border lines to maximize the import capacities in real time. DLR was operational during the winter, and, following interesting gains generated in real time during this period, Elia decided to

implement two-day ahead DLR forecasts for the next winter 2015-2016 to offer additional exchange volume to the market.

WINTER 2014-2015 BELGIAN GRID SITUATION

In summer 2014, the loss of three nuclear power plant of about 1000 MW each (the Belgian peak load is around 13000MW) highlighted a risk of shortages during the winter in case of severe weather conditions. Belgium can import electricity from neighbouring countries via its border lines, but the maximum import capacity based on traditional seasonal rating of the border lines could be not sufficient with specific situation like cold waves on Europe.

The DLR concept with Ampacimon technology had been applied in Belgium for 3 years on several domestic lines and Elia was aware of its potential. To maximize imports in real time and reduce the risk of load shedding during the 2014-2015 winter, Elia decided to implement DLR on all critical border lines with France and Netherlands.

PROPOSED SOLUTION

Belgium has 10 border lines with France (6 lines) and the Netherlands (4 lines). Elia decided to equip the 8 most critical ones with Ampacimon sensors, and to operate them with a dedicated real-time and forecast monitoring software.

For the supervision of a line, it is necessary to install Ampacimon sensors on all critical spans (i.e. spans crossings of roads, crossings of railways, near forests or where sheltering trees limit the wind speed …).

For those tie lines the conductor types are different on each side of the border and the capacities of the lines are always significantly lower on the Belgian side. Therefore, the first possible quick win was to only equip the Belgian side.

In agreement with neighbouring TSOs RTE (France) and Tennet (The Netherlands), it was decided to operate the border lines by using 2 limits: (i) a dynamic limit for the Belgian side and (ii) a static seasonal limit for the other side. For each border line, the capacity is calculated as the minimum of these two limits.

DLR had to be operational before winter 2014-2015 and the time was limited. Thanks to the fast commissioning of on-line sensors, the following work plan has been realised as planned:

- August: Elia decision to implement DLR on critical Belgian border lines
- September: Principle agreement with neighbouring TSO RTE & Tennet
- October: Agreement with neighbours about operational limits
- November: Finalize sensors installation
- December: Operational DLR integrated in the SCADA

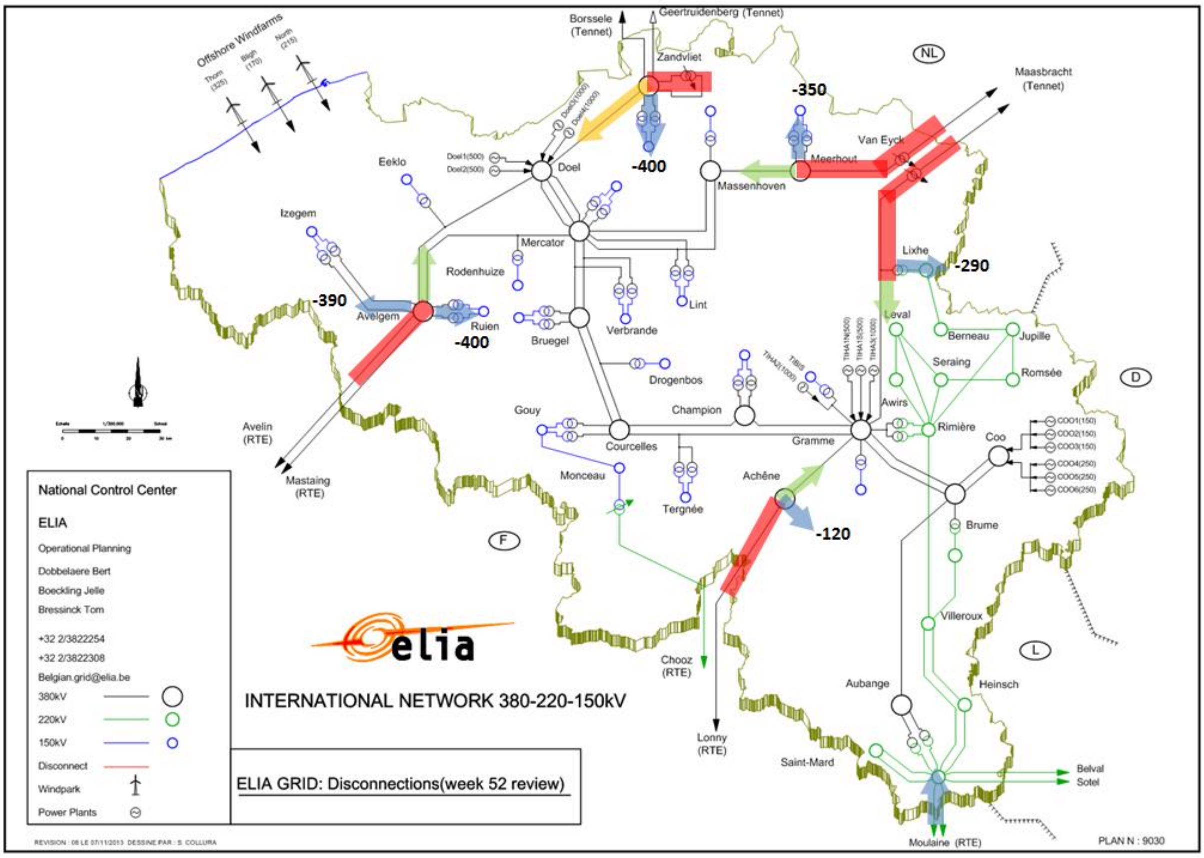

Figure 1: Elia high voltage grid

The Ampacimon sensors measure the span sag and perpendicular wind speed. Based on sag and wind speed, the real time rating is computed for each span and for the whole line. A short-term forecast is also computed for the next hour and the next 4-hours. These forecasts ratings are transferred to the Elia SCADA every five minutes.

For operations purposes, it is necessary to have a stable value during an hour to allow calculations for the grid security assessment and to give operators sufficient time to react to possible incidents. The N-1 calculations are automatically performed every 15 minutes using the 1-hour forecast rating instead of the seasonal rating.

While thermal rating (wind cooling) can provide increases over 200% of the seasonal rating, other equipment (transformer, circuit breaker ...) have lower limits. The rule applied for Belgian lines limits the gain generated by dynamic rating to 130% of the seasonal rating. If an equipment in the chain cannot meet the 130% rating, the maximum line rating its adapted to the limiting equipment.

This fully automated process allows integrating the real-time measurements from the sensors up to the grid security assessment without the intervention of the grid operator.

TWO DAYS-AHEAD FORECAST METHOD

Day(s)-ahead ratings forecasts need weather forecasts as beyond a horizon of about 6 hours, it is no more possible to use time series forecast method. Solely weather-based rating forecast provides the trend of the real-time rating for the following days, but fails to give reliable rating forecasts, mainly due to wind speed forecast uncertainties[2] (Figure 3), in particular for wind speeds whose component perpendicularly to the conductor axis is lower than 2-3 m/s (such low wind speeds are critical for rating determination). Moreover the weather forecasts should be provided with enough spatial and temporal resolution to meet the need for day-ahead rating forecasts and line rating operation; which is very difficult and/or too complex to be modelled explicitly in meteorological models and/or digital terrain models in practice since wind speed and direction can vary significantly over the distance of a span and/or a section. Indeed, in climatology high wind speeds (typically measured by weather stations above 5 [m/s] at 10 meters height above ground level) are related to macro-scale effects but low wind speeds mainly result from local effects generally related to the local topology and screenings (trees, buildings,…), terrain roughness, conductor level, turbulence, the atmospheric boundary layer effect, … Some of these low winds may also be very non-directional and very variable [9], which further complicate their forecast.

Moreover a guaranteed rating forecast should be delivered, so that the TSO is able to use it in practice; as it is the case for real–time measurements. Indeed, in operational practice, the main concern of TSOs is the overall management of risk. Day-ahead rating forecasts must be extremely reliable, i.e., with a high confidence level (of at least 98% as it is the case for conventional seasonal/static ratings today to ensure secure operation of the grid); in others words, the probability for the forecast to be lower than the real-time rating should be at least 98%.

In practice ambient temperature can be forecasted with very good accuracy and maximum sun radiation could be predicted theoretically with very good accuracy as well. We are thus able to take advantage of that fact and determine a reliable forecast for worst–case weather conditions ; the minimum rating forecast is based on conservative assumptions : perpendicular (to the line, to each span) component of wind speed is equals to a minimum value depending on utility's operations rules (i.e. 0.55 [m/s] in Belgium), with the maximum theoretical solar radiation and ambient temperature forecast raised by a given value (i.e. from 2 to 5°[C]) to ensure no overestimation of the actual rating. This provides a minimum forecast gain called Ambient adjusted forecast rating (AAFR).

However, this corresponding lower-bound (minimum) relative gain to static seasonal rating would not have relieved all specific congestion cases nor prevented topological and/or costly dispatch actions. A value of about 120% (relative to seasonal rating) rating is high enough to reduce congestions in practice but this value is not reached using only ambient temperature forecasts; this is why the wind effect has to be taken into account. The lines can be dynamically rated at higher levels thanks to the wind cooling. This Additional gain (due to wind cooling) can be taken into account when forecast wind is adequately considered; as previously explained local effects must absolutely be taken into account.

Raw forecast weather (mainly the wind at conductor level) has to be modified based on observed measurements; we speak about degradation of forecast weather. The degradation algorithm is computed based on the history of weather forecast and history of real-time measurements from on-line sensors measuring sag and perpendicular (to the line) wind component data over several weeks/months (ideally at least a season, a full year or more is even better). This degradation is regularly updated to take into account potential changes of

[2] and/or also due to potential low quality topographic mesh and/or or unknown local topographic, terrain roughness

weather conditions due to changes in season conditions or due to changes in the forecast model.

Based on the real-time historical data measured by Ampacimon sensors, we can statistically adapt the weather forecast to locally observed conditions (as viewed by the line/conductor) of each (critical and monitored) span. Degradation of the weather forecast is computed so that the forecast is below real-time during a given confidence level (for example 98% of the time). This Ampacimon method based on statistical degradation using the history of real-time measurements at conductor level allows to take into account local conditions as measured on-site (to keep the given level confidence, typically 98%), as illustrated in Figure 2. It is thus a robust corrective control of forecast weather since all local effects (as measured/observed by on-line sensors) are considered.

The actual aim of the rating forecast is not to provide the most accurate value to the real-time rating (in a least squares sense), but to provide the lower-bound on the real-time rating, such that TSOs are ensured to have at least the predicted rating values actually available in real-time. The forecast algorithm is developed according to these specifications and special attention is given on rating forecasts overestimation: the ratio of overestimation must be minimal. This is automatically included in the degradation process using the history of real-time measurements from on-line sensors.

The degradation process is site-dependent and the developed degradation algorithm directly includes that dependency as Ampacimon on-line sensors measure sag and (perpendicular to the line component) wind speed at all identified critical spans location. Thanks to Ampacimon conductor vibrations-based direct monitoring technology, low wind speeds are accurately measured as seen by the spans (line) at conductor/line level. This accurate measurement allows prior information about the critical wind speeds range for line rating to be incorporated into the degradation process and boosts the forecasting rating performance by safely and carefully considering gains related to wind speed and by minimizing the risk of wind speed overestimation at critical ranges.

A single spot weather station near the line would have to measure local effects for the power line, which would need to be installed at the conductor level. The only practical way is to install them on towers where energy would be needed for data storage and remote transmission. A weather station is then obviously giving a local measurement (not a “span” value as deduced from the Ampacimon sensor on the line) and (low) wind speeds can be quite different along aseveral hundreds of meters span. As detailed in Cigre 2014, paper B2-208 [6] “There are no commercial meteorological services that monitor these low wind speed levels along the line. Even a distributed network of anemometers privately owned by utility would require too extensive a deployment of instrumentation to be viable”. As it is true for real-time monitoring of power lines it is true for forecast and/or fit meteorological models to local measurements using a widespread spread system of local observing weather stations as well. Moreover, using only Meteorological data and models as a method to determine lines rating and forecast rating is therefore not safe, while there are actually safe alternatives using direct on-line monitoring, in particular the ones monitoring the sag and the wind speed.

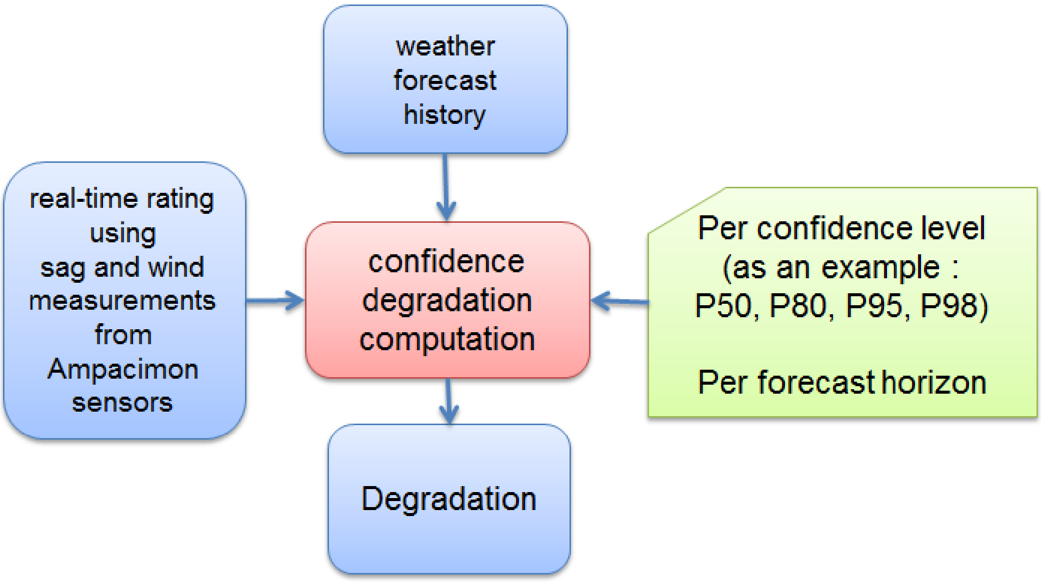

Figure 2: computation of degradation using history of forecast weather and history of real-time measurements (mainly wind measurements) from on-line sensors

In addition, this method has the advantage to give some control on the prediction interval, depending on the safety margin needed. Here, the chosen value was 98% confidence. The confidence interval of the forecast may be adjusted to operational needs, as a trade-off between more gain and more confidence in the forecast rating has to be set, depending on the risk policy of the utility. In contrast, the Ampacimon rating forecast algorithm provides a safe forecast, though with less gain than the actual rating measured in real-time (see Figure 3).

Figure 3 shows the time evolution of day-ahead forecast ratings before (solely using (raw) weather forecast data) and after application of the degradation algorithm. Forecast ratings can be easily compared to real-time measurements. Minimum forecast gain (Ambient adjusted forecast rating (AAFR), based on fixed perpendicular wind speed, forecast ambient temperature and maximum theoretically forecast of solar radiation) is also shown.

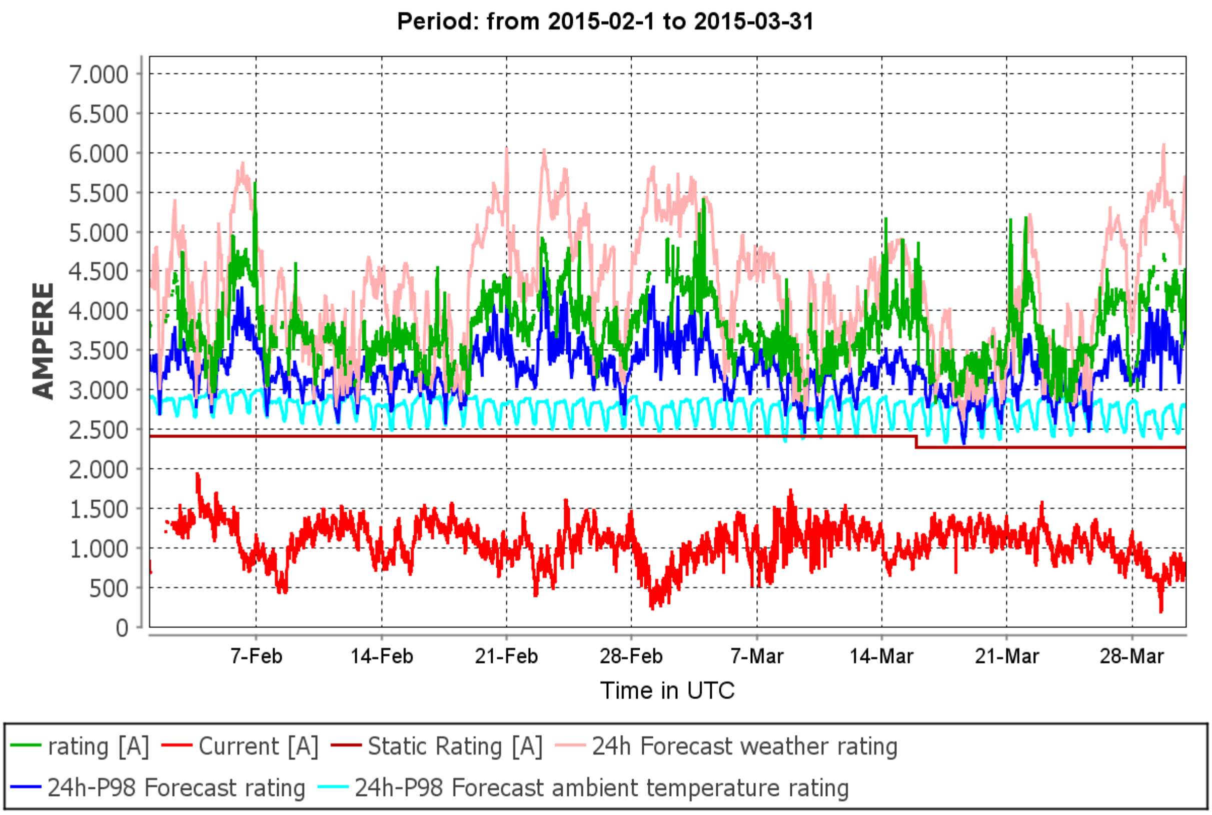

Figure 3: Time evolution of day-ahead forecast rating compared to real-time measurement and seasonal rating. (rating) dynamic real-time rating, (Current) current, (static rating) seasonal rating, (24h Forecast weather rating) weather day-ahead forecast rating (before degradation process), (24h-P98 Forecast weather rating) forecast rating after degradation process to ensure that real-time rating is not overestimated at least 98% of the time and (24h-P98 Forecast ambient temperature rating) ambient adjusted forecast rating.

The forecast algorithm developed aimed to provide rating forecasts with a controllable confidence interval on the rating overestimation risk. It succeeded in its purpose because weather forecasts were considered in a new way with a clear emphasis on low wind speed period forecasting owing to online sensors used as tuning data. Despite high sensitivity of dynamic rating with respect to low wind speeds, typically hard and difficult to measure by local weather stations and difficult to forecast, satisfactory results were obtained, and validated in the field.

It is important to keep in mind that whatever weather and DLR forecast models are used, forecast errors will happen, real-time monitoring is thus a necessary condition to control the rating in real-time and, ultimately, the sag using Ampacimon sensors/technology to ensure safety and security, as it provides continuous monitoring and operational awareness of the actual state of the lines to utilities.

During daily operation, the short-term 1h forecast is also used to manage the operational security of the grid.

Forecast delivery sequence

Forecast weather data from RMI (Royal Meteorological Institute) computation starts for all monitored critical spans locations every 6 hours (00H, 06H, 12H, 18H) using meteorological models. Once these weather forecasts (up to 60 hours with a time step of 30 minutes) are available after computation time (from 4 to 5 hours computation time), rating forecasts are computed using weather forecasts and computed degradation as explained above.

Day-ahead forecast for the market

In spring 2015 generation problems were still present in Belgium and in preparation of the 2015-2016 winter, Elia decided to implement the day-2 DLR forecast. The decision regarding network operations and Electricity Market are taken 2 days in advance. By providing the market tool “Flow based” dynamic limits, we already give in day-2 a portion of the generated gain by DLR.

A small gain on a limiting line can give a significant gain for the market and has an impact on security margins and electricity prices.

FIELD RESULTS

This section presents the gain obtained by dynamic rating during winter 2014-2015 on cross-border lines. First, the two days ahead forecast results are presented. Then, the real-time rating results are showed and finally some economical results are highlighted.

Two days ahead forecast results

The Table 1 shows the results of the 48h forecast relative to the static seasonal rating from December 2014 to February 2015. On line 1, in average the 48h forecast is 119% of the static seasonal rating. During 90% of the time, the 48h forecast is above 112% of the static seasonal rating.

Table 1: 48h forecast rating statistics on winter 2014-2015

Line name	Average	Minimal value 90% of the time
Line 1	119 %	112 %
Line 2	117 %	109 %
Line 3 (near the sea)	122 %	113 %
Line 4	116 %	108 %
Line 5	115 %	108 %

The Table 2 shows the 48h forecast confidence. A forecast is considered confident if it is lower than the real-time rating at that time. On line 1, the 48h forecast is lower that the real-time rating during 98.3% of the time. Usually, the over estimation occurs at high wind speeds that are highly overestimated in the weather forecasts If the forecast is limited (i.e. capped) to a given threshold for instance 115% or 130% of the static seasonal rating (such capped values are used in practice by TSO to reflect the fact that other systems – such as substation equipment – might limit the overall transmission capacity anyway), the confidence is even higher. With a 48h forecast capped to 115% of the static seasonal rating, the confidence reaches 100% on all lines.

Table 2: Confidence of the 48h forecast on winter 2014-2015

Line name	Confidence	Confidence with	Confidence with

		rating capped to 115%	rating capped to 130%
Line 1	98.3 %	100 %	99.4 %
Line 2	97.5 %	100 %	98.6 %
Line 3 (near the sea)	97.1 %	100 %	100 %
Line 4	99.6 %	100 %	100 %
Line 5	100 %	100 %	100%

Real-time results

Table 3 shows the results of the real-time rating during the winter 2014-2015 (December to February). The real-time rating is relative to the winter seasonal rating. The table shows the average rating and the minimal rating occurring 90% of the time.

For line 1, in average the rating is 138 % of the static seasonal rating. For all lines, the rating is above 132 % of the static seasonal rating on average. During 90% of the time, the rating is above 121 % of the static seasonal rating.

Table 3: Real-time rating statistics on winter 2014-2015

Line name	Average	Minimal value 90 % of the time
Line 1	138 %	130 %
Line 2	136 %	126 %
Line 3 (near the sea)	156 %	142 %
Line 4	132 %	121 %
Line 5	143 %	130 %

For grid operation, the real-time rating is not useful since it comes too late to anticipate actions. The operator prefer to use the forecast-1h rating. The forecast-1h rating estimates the rating for the next hour. The forecast-1h rating is computed to be lower than the real-time rating during more that 98% of the time. The objective is not to estimate the best possible forecast (reducing error with real-time rating) but the more confident forecast (reducing the over-estimation error of the forecast regarding the real-time rating). The forecast-1h is a conservative value that can be used safely by the TSO to operate the grid.

The following chart shows the load duration curve for the real time rating (called ampacity in the chart) and 1h-forecastrating on one line from the 1/1/2015 to the 1/7/2015.

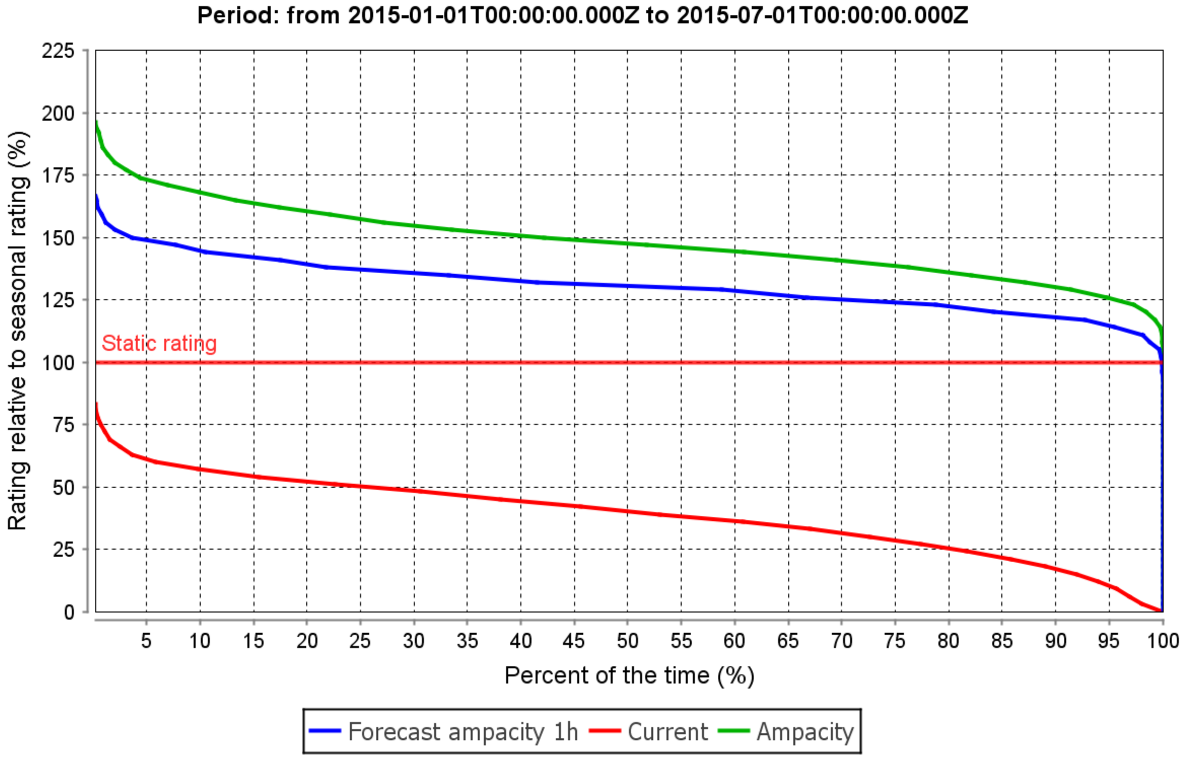

Figure 4 : Real-time and forecast-1 load duration curve

Over one year of monitoring, different congested situations have been observed. During the winter period 2014-2015, the lines from the Netherlands were highly loaded due to important flows from the Netherlands to Belgium. During the summer period, the dominant flows shifted from the Netherlands to the French border. The 380kV lines from France became highly loaded.

From September to October, during severe grid situations, the dynamic rating was absolutely necessary to safely manage the network.

As explained, each cross-border line was critical at a given moment due to changing flows and grid situations. As a consequence in that case (Belgian grid monitoring), it's important to monitor all the selected cross-border lines.

Economical results

As stated earlier, a reliable D-2 forecast can improve the results of market coupling which aims at maximizing the day-ahead market welfare.

If the market coupling methodology is Flow-Based (like in Central Western Europe since 21/05/2015), one can also prioritize the installation of dynamic line rating sensors. Flow-Based market coupling allocates the cross-border capacity for international exchanges by taking into account the impact of these exchanges on the grid elements and more particularly on the scarce capacity of the specific high-voltage grid element(s) constraining the cross-border exchanges. The impact of exchanges between two hubs on one specific grid element is modelled by a factor usually called PTDF (for Power Transfer Distribution Factor).

The key equation of Flow-Based methodology links, for each allocation period (usually 1 hour), the price spread between two different hubs with the PTDFs of the grid element constraining the energy exchanges. For a specific limiting constraint, this ratio is equal to the « shadow price » of the grid element, which is the amount of additional market welfare that would be generated if one extra MW was made available on the constraining grid element.

Flow-Based methodology allows associating to each hour the exact grid element constraining the exchanges in the coupled area. And an average shadow price can then be computed for recurrent bottlenecks in the high-voltage grid.

This is particularly useful for prioritizing the installation of dynamic line rating tools. Additionally, Flow-Based methodology allows valuing the gain for the community of the coupled area corresponding to one additional MW of scarce capacity made available for market exchanges.

Flow-Based constraints define a domain in which the market can clear without endangering grid security. If the market clears inside this domain, it means that the energy exchanges are not limited by grid elements and this will result in full price convergence in the between the hubs. On the contrary, when the grid capacity limits the market, the clearing point will be at the border of the Flow-Based domain, on the constraining grid element.

A few extra MW made available on this specific limiting element can allow significantly higher exchanges between two different hubs (depending on the Power Transmission Distribution Factors (PTDF) of the constraining grid element) as only a part on the energy exchanged between the two hubs loads the limiting element.

To quantify the economic benefit of the 2-days ahead forecast dynamic line rating, we performed a simulation of the "Flow-based market coupling" in the CWE region with and without Ampacimon DLR 2 days-ahead forecasts. For example, on 19/2/2015, the market was limited due to Belgian import capacity. By using the 2-day ahead forecast, this limitation would have been less constraining. During this 4 hours period only, the gain of the forecast on the CWE welfare has been computed to 247.250 €, with an additional import for Belgium of 33MW.

CONCLUSIONS

This paper presented a case study where Dynamic Line Rating and Dynamic Forecast Rating have been used to tackle congestion problems on cross-border lines in a matter of months. This DLR project was operational early in November 2014 and has been working since then.

Dynamic rating allows to uncover the actual imports capacity based on real-time observed weather conditions. Direct Real-time monitoring allows to manage the grid with a higher level of security as compared to present practice (seasonal ratings) since the actual sag conditions are measured.

Results also showed that significant accurate and reliable gain is also available and possibly predictable in days-ahead horizon as well. This was observed for all monitored lines for different weather and terrain conditions; some lines are close to the sea and located in flat open terrain (BE-NL border) and some lines are located in hilly and wooded terrain (BE-FR border).

During 90% of the time, the gain (relative to seasonal rating) is higher than 20% of seasonal rating. Observations and analysis have shown that days-head yielded an average of about 10% gain over seasonal ratings.

These particular values cannot obviously be generalised to all cases in the world, and real-time and forecast gain over seasonal rating are line-and-location dependent but these pioneering results show evidence that a substantial gain over seasonal rating is indeed available and possible, and that ratings can be reliably forecasted over a few days horizon with a high level of confidence.

Integrating field measurements from on-line sensors into the forecasting algorithm improved its reliability. This methodology predicted 2-day-ahead ampacity with 98% confidence (meaning that capacity forecast was overestimated in just 2% of cases). The method also allows to controll the level of confidence.

In order to avoid the uncertainties of the forecasting models, Ampacimon forecast software automatically adapt weather forecasts to fit local conditions as measured at line level. It means that if the weather forecast is highly representative of local conditions at line level, weather forecasts will only be slightly adapted and the quality of the forecast ratings is mainly driven by quality of weather forecasts. In case of poor quality forecasts at line location, the developed auto-adaptive method will still ensure high confidence (by construction) but potentially lower gain. As a main conclusion, the Ampacimon method can be generalized to any location, and, moreover, independently of weather forecast quality.

As soon as days-ahead extra-capacity forecasts are available on the electricity market, power flows on different lines will increase since the market uses the newly available extra capacity. Reliable direct on-line real-time dynamic rating monitoring (especially systems measuring sag/clearance conditions) by network operators is a precondition for safely exploiting this extra capacity.

Combining more accurate forecasts with real-time measurements at line location provide an innovative and useful tool to manage flows through existing networks without jeopardizing system security.

As showed from the economical point of view, a small increase of the cross-border line has a significant impact on the market price. Our field results show that Dynamic Line Rating can provide immediate benefits in today’s networks.

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