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Weather forecasted thermal line rating model for the Netherlands

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SUMMARY

When transport capacities, that are based on dynamic rating, can be made available to the market, this will lead to the highest benefit for the customers. In the Netherlands this means that reliable forecasts would be available one and two days ahead of the actual transport. Weather forecasts for wind speed and air temperature together with the spread around the expected values can be taken from existing weather forecasting techniques.
The net relative cooling of overhead conductors is defined, with 100% capacity standing for a conductor at 80 ^{0}C at a 0.6 m/s right angle wind in 30 ^{0}C air in 1000 W/m^2 sun. When the weather parameters change, a relative transport capacity is prorated to the 100% capacity. One transport value can then be applied more or less irrespective of the conductor, solely dependant on the weather parameters.
Predictions for each tower location are based on interpolated weather station forecasts and a high resolution roughness map. The line prediction is the aggregate of individual spans, where the lowest capacity sets the capacity for the whole line. The most unfavorable angle between line and wind is used for the capacity calculation. Since the weather stations and the roughness map cover the whole country, all lines can be handled with this model.
The model developed gradually as a joint product of line engineering, operational knowledge and meteorological experience. After an introduction to the model, observations from an 18 months pilot are discussed, showing a large possible average capacity gain on the pilot line. The probability level of the forecasts can be selected as is appropriate for the particular transport situation. Incidents of significant overestimation, this is where the calculated capacity with actual weather parameters remains below the capacity calculated with forecasted parameters, are reviewed in terms of frequency, duration and magnitude.
Further refinement of the model will be undertaken in the next phase of the pilot project.

KEYWORDS

weather, wind, wind speed, dynamic rating, thermal rating, overhead line, roughness, line prediction

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Serving the market

It is a challenge to rate the transport capacity of the electrical circuits to a safe maximum. The existing infrastructure is there to serve the market demands as best as possible, which includes capacity and security of supply. In general for the overhead line part of the circuits, the available space to the ground in each span (room for maximum sag) determines the maximum allowable conductor temperature and with that the thermal rating. The rating calculation starts with a heat balance around the conductor under fixed circumstances describing the cooling of the conductor in a deterministic way. Since these fixed circumstances are not representative for the actual cooling during most of the year, solutions are sought to link the rating to a more representative cooling, as seasonal rating or some form of dynamic rating. Real time monitoring of local weather parameters or real time monitoring of direct measured sag are examples of the use of more accurate information to establish the actual thermal rating of that moment.

Real time solutions can help out in operational situations, but since the network in the Netherlands operates under a N-1 principle, also during maintenance, there are very few moments that real time rating would really help. But if increased ratings could be released timely for transport programs or for scheduling programs, say one day or two days ahead, than the gains in capacity can be passed on to the market. For the Netherlands the highest value of dynamic rating can be reached with methods that determine the rating with sufficient accuracy some days ahead. This study produces such rating in a reliable way.

In the Netherlands, there are two moments of interest that are considered. With the day for which the transport programs are made defined as d, than two days before, on d-2, somewhere in the morning the available transfer capacity for the interconnectors to Belgium, Norway, United Kingdom and Germany are exchanged and agreed. On d-1 in the afternoon the inland transport programs for all connected parties are checked for grid security and agreed.

A rating model is developed to yield ratings for each hour of the day, at least two days ahead. Preferably the model would be applicable all over the country.

Net cooling

The thermal model will not be tied to one particular conductor, or one particular span, but will be general for typical existing configurations. To determine the transport capacity, solving the heat balance around the conductor is not required; knowing the net cooling duty (W/m) is sufficient. A fixed design conductor temperature is assumed and the sun radiation, outside temp, wind speed and wind angle are input variables. The cooling at T_{cond} 80 ^{0}C, 1000 W/m^2 radiation, T_{air} 30 ^{0}C and wind 0.6 m/s at 90^0 is set at 100% cooling capacity. This is also100% for transport capacity, which is the design capacity of the line. Increasing the net cooling to for instance 200% (for instance due to high wind speed) leads via the relationship heat = I^2.R to 140% transport capacity. The effect of conductor parameters is only marginal in this approach. In figure 1 the graph is shown for a 28 mm diameter conductor using the formulas from Cigré TB207 [1]. The transport capacity is strongly dependant on the wind speed and wind angle. The 100% capacity point is marked is this graph. This graph shows also that situations will occur in which the familiar 100% may not be reached.

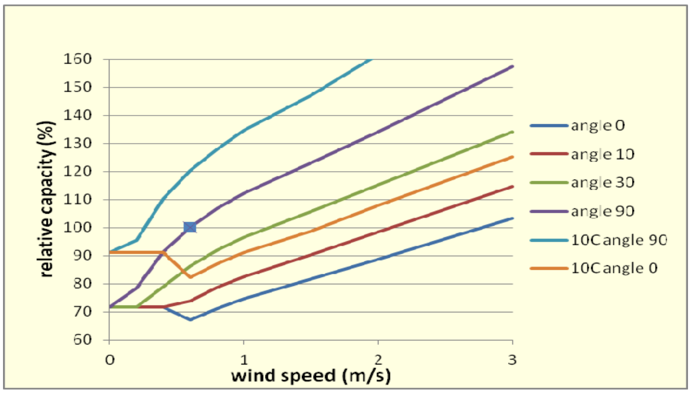


Figure 1 Relative transport capacity in %; conditions: T_{air} 30 and 10 ^{0}C, T_{cond} 80 ^{0}C, sun 1000 W/m^2.

Weather forecasting

Two common parameters of numeric weather models are wind speed and temperature. With statistical post processing techniques these numeric weather forecasts are unbiased by using local weather station observations. The accuracy of these forecasts is known from long history observations. By interpolation between weather stations, every location on the map can be served with its own forecast. That is the basis of the model developed here. There are however a few problems to solve.

The first is that the wind forecasts are for weather stations that are normally located on open terrain like airfields. A correction for terrain roughness in the vicinity of the line has to be made. A national roughness map in a grid of 100x100m is used. Figure 2 illustrates how the wind forecasted for open terrain (point 1) via the meso wind (point 2) is converted, using standard wind formulas, to a height of 10m in our actual span (point 3).

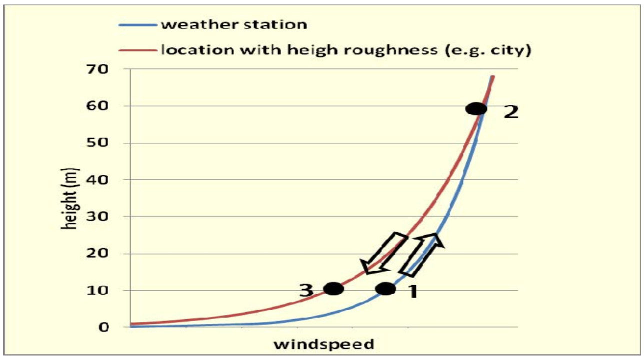


Figure 2 Sketch to correct for ground roughness

The second concern is the geographical spread. Two adjacent weather stations may have very similar wind climatology, but with a unsatisfying correlation between the single hourly observations. With the 100x100m grid, individual predictions for each span or tower can be made. The overhead line then is the aggregate of all spans between two substations, in which the span with the lowest capacity determines the capacity.

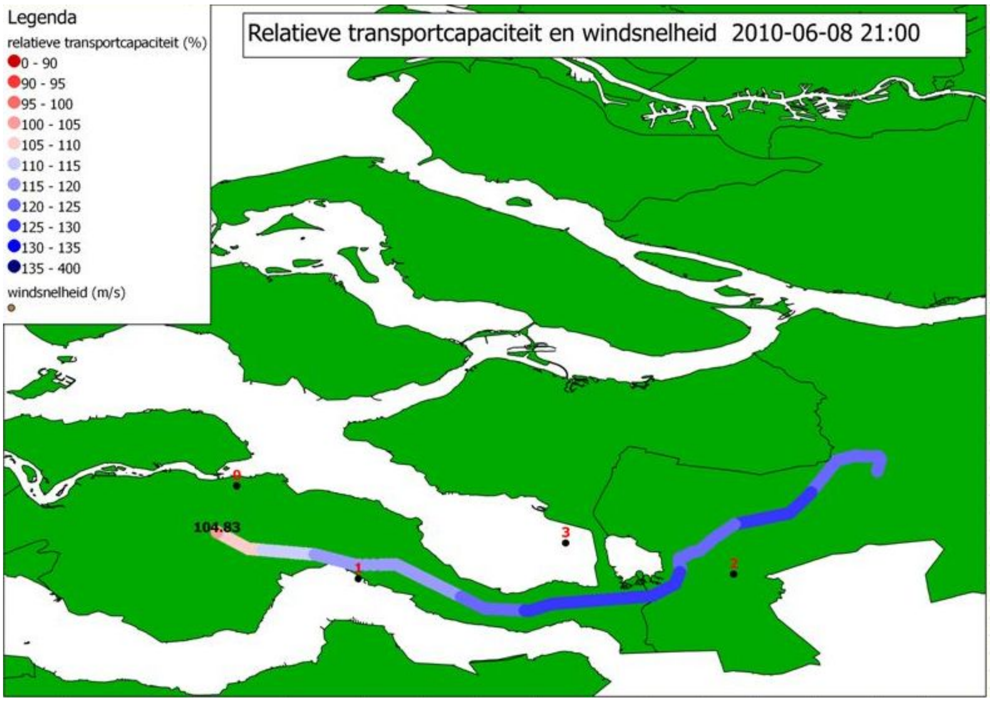


Figure 3 Map of the line in the pilot, calculated transport capacity for each tower indicated by colour coding.

Figure 3 gives an example of a line on a map. The four weather stations that determine the input to calculate the conditions on the tower locations are indicated with the numbers 0, 1, 2 and 3. The limiting span moves as the local weather moves, but in general the spans with high surface roughness appear as the limiting spans. The use of line predictions leads to a more precise forecast compared to use of regional forecasts for lines.

A third concern is that parallel winds may happen along overhead lines. As the estimate for the wind direction has a large spread and as a line between two substations may contain sections that are in a right angle to each other, care has to be taken. However, the wind direction is not constant during an hour. Especially during conditions with low wind speeds, the wind direction has a relative large variation. In figure 4 the effective wind angle as a function of the 10 minute wind speeds is given. In our study these angles are applied in the cooling calculation. In particular at higher wind speeds these angles lead to very conservative cooling rates and thus calculated capacities.

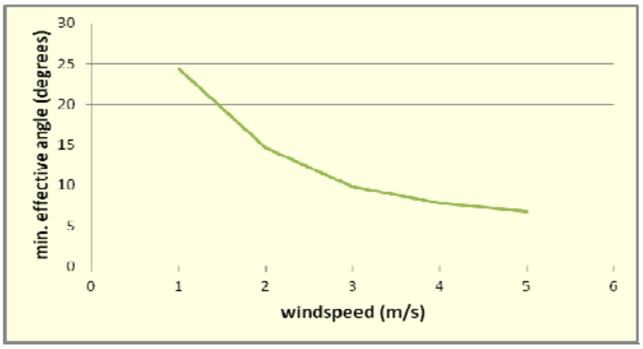


Figure 4 Effective wind angle as a function of wind speed.

<u>The model will calculate also capacities below 100%</u>
When the wind angle as described above is applied, the transport capacity as in figure 5 results. A wind speed of appr. 1.8 m/s is required at an ambient temperature of 30 ^{0}C to reach a calculated capacity of 100%. With a temperature of 10 ^{0}C (approximately the year average value in the Netherlands) a wind speed of more than 0.5 m/s is needed to reach 100%. This is only because a conservative angle between the wind and the span is assumed. Using the assumptions of unfavorable wind angle and actual roughness, the forecast of the capacity may be below 100%.

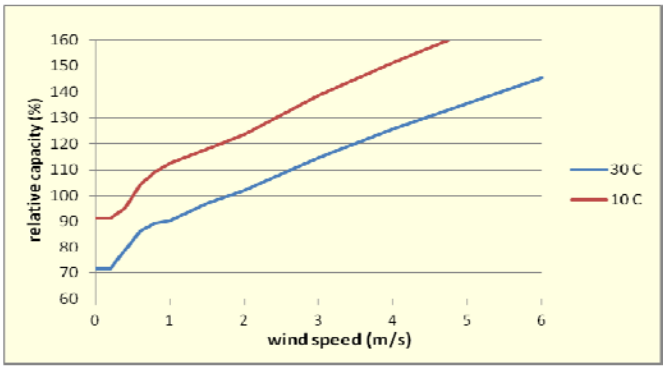


Figure 5 Effective transport capacity including the wind angle; 100% capacity is at 0.6 m/s right angle wind and air 30 ^{0}C. Conditions: conductor temperature 80 ^{0}C, sun 1000 W/m^{2}.

Periods with calculated capacities below 100% occur in the Netherlands between 0.3% of the time (coastal provinces in the west) and 1.4% of the time (one province in the east). Since this is the situation before applying a dynamic rating, it indicates a level of confidence that goes with the adopted conservative capacity calculation. Periods with low capacity do occur most frequently in summer and during the night, when low wind speed wins from the absence of the sun. Incidents of capacities below 100% generally last only a few hours, 78% of these incidents last only 1 hour, 16% last two hours.

Reliability of the forecasts

The uncertainty of the weather parameters in the forecasts is a function of the type of weather and the time length of the forecast. Other variation is introduced by using one observation for each clock hour (typically the 10 minute average before the full hour) and the accuracy of the wind measuring equipment at low wind speed. These errors lead to a standard deviation in the calculated transport capacity. The expected value is the P50, which means that in 50% of the cases in this forecast the actual capacity will be higher than the forecasted capacity, and in the other 50% the capacity will be lower. A P80 forecast stands for the value where in 80% of the cases the actual capacity will be above the P80. Typical standard deviations of the capacity move from appr. 12% (tomorrow morning) to 16% (day-after-tomorrow evening).

One way of representing the influence of the reliability is illustrated with figure 6. On the horizontal axis are the clock hours of d-1 and d. The vertical axis gives the percentage of forecasts in summer with a capacity exceeding 100%, 125% and 150% of the design capacity. The wind generally picks up in the afternoon, leading to higher capacities, some predictions will show capacities below 100%.

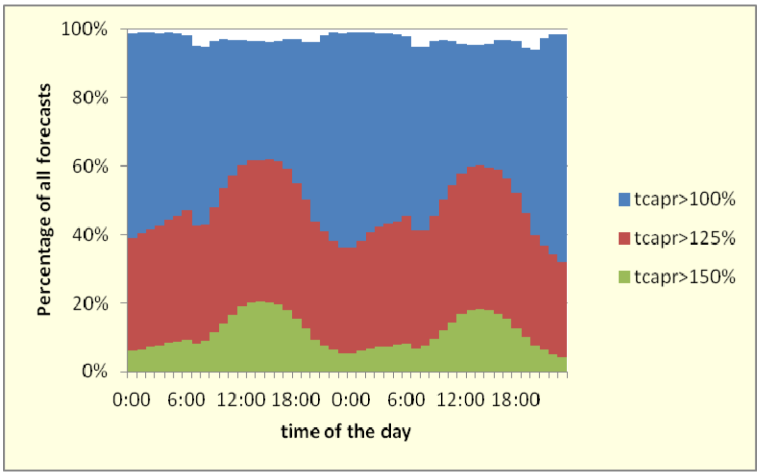


Figure 6. Percentage of all forecasts during the summer with a probability of more than 80% on a certain relative transport capacity (tcapr) threshold

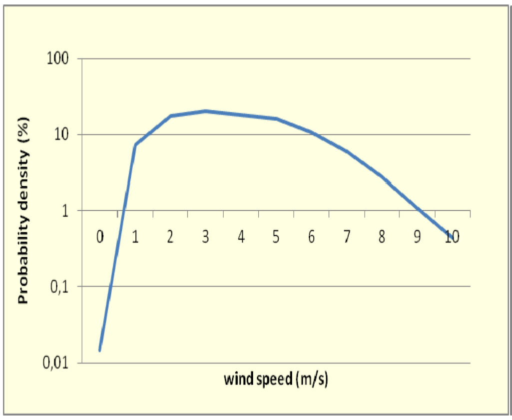
Pilot for a 94 km line

The approach described in above paragraphs has been applied on a line in the south west of the Netherlands using weather datasets covering the period from 11-3-2009 to 30-9-2010. This pilot is in fact a hindcast: capacities based on actual weather parameters were compared to capacities based on forecasts of weather parameters for that clock hour issued respectively two days, one day and four hours ahead. Capacity forecasts for probabilities P50, P60, P70, P80, P90, P95 and P99 were calculated.

This pilot reveals aspects as:

- the wind characteristic
- the capacity available as a function of the forecast reliability
- the accuracy of the average prediction
- overestimated capacities, magnitude and duration

The typical wind profile based on the observed wind in the critical span is given in figure 7, which shows the probability density during this period. In this part of the country low wind speeds are rare, winds between 1 m/s and 6 m/s do occur with similar frequency. This promises a large potential for dynamic rating compared to a standard 0.6 m/s.



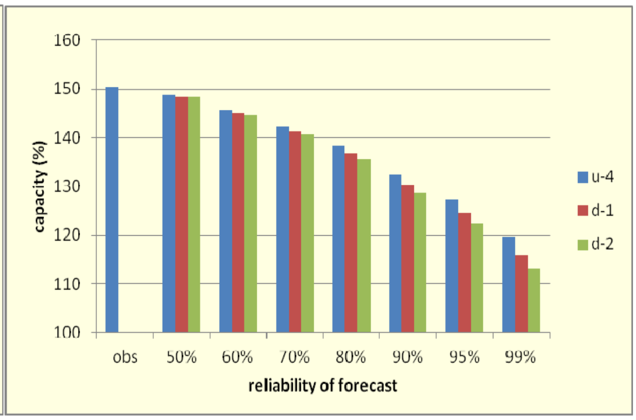
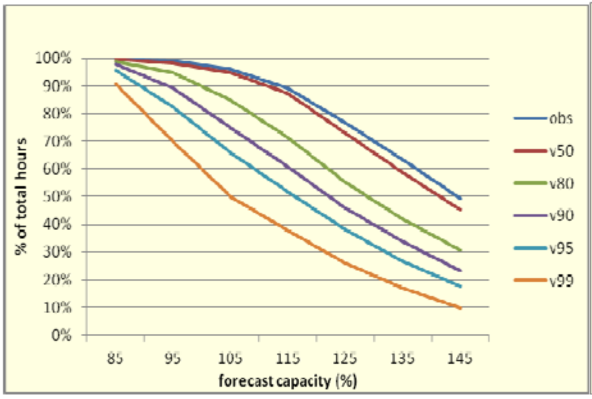


Figure 7 (left) Probability density from wind on critical spans
Figure 8 (right) Average capacity as a function of the reliability of forecasts

The average values of the forecasts are given in figure 8. As can be expected, the more reliable the forecasts need to be, the larger the distance between the expected value (P50 ≈ observed value) and that forecast. Also, the effect of the time between the forecast and the moment of interest is visible.

When two-day ahead forecasted capacities, grouped in classes of 10 percent-point, are counted, figure 9 can be drawn. It shows the number of hours with a minimum predicted capacity with the probability as the running parameter.



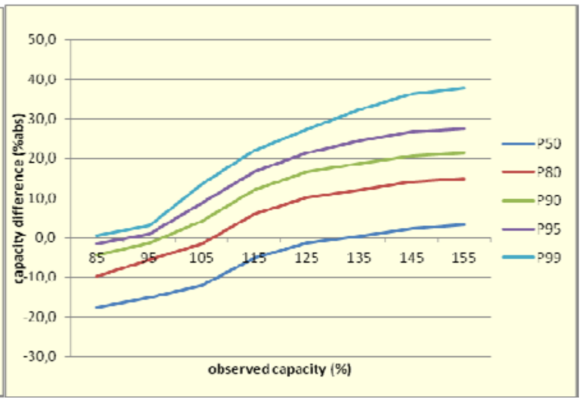
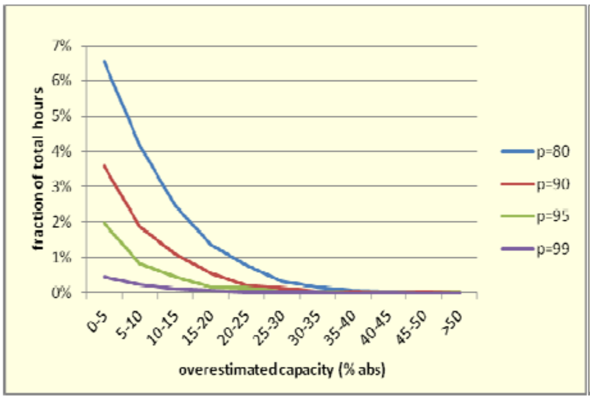


Figure 9 (left) Fraction of total hours with forecasted capacity in or above given classes
Figure 10 (right) Average difference between observed and forecasted capacity, d-1

To asses the accuracy of the predictions, the observed capacities are compared to their predicted values. In particular overestimated predictions are of interest. With the P80 forecast always 20% with overestimated capacities will remain, so overestimation will happen.
Instead of using the predicted capacity, now the observed capacity (that is the capacity calculated with observed weather parameters) is the starting point. In Figure 10 the average deviation between predicted and observed capacity in %abs is presented. It shows a bias, originating from the fact that very low observations rarely were preceded by even lower predictions. Creating distance by increasing the reliability level, does help, but to the expense of losing capacity over the whole capacity range.

The magnitude of overestimation is of interest, since minor errors may well fall underneath other conservative assumptions, but major errors could lead to significant problems. In figure 11 the occurrence of the overestimated values is shown. The larger errors are an invitation to identify their origin and try to reduce their magnitude and frequency further.



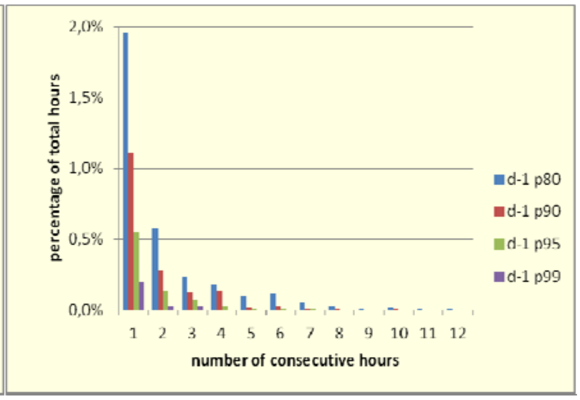


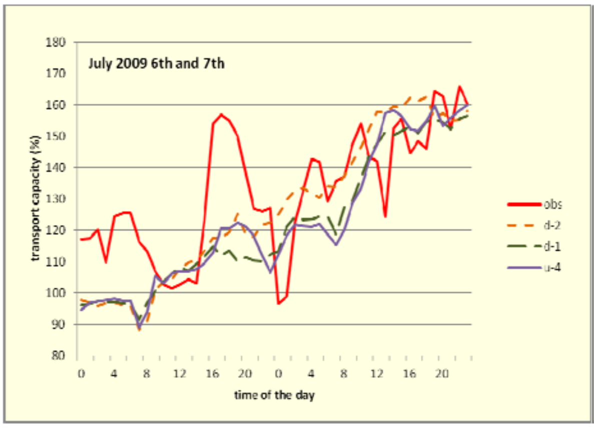
Figure 11 (left) Fraction of total hours with overestimated capacity in classes, d-1; filter: observed capacity < 150%.
Figure 12 (right) Fraction of total hours with overestimated periods, d-1; filter: overestimation > 5%, observed capacity < 150%.

The duration of overestimated periods is illustrated in graph 12. Most periods of overestimation lasted only for one hour. Increasing the reliability in the forecast has a clear reducing effect on the number of consecutive hours of overestimation.

In the next section two cases illustrate situations where there was a remarkable overestimation of the capacity.

Case 1

In one period of 48 hours several occasions were encountered where the forecasts were higher than the calculated observed capacity. This occurred in a period of unsettled weather conditions, characterized by a large variation in wind speed over time. The data are presented in figure 13. The periods of overestimation lasted only a few hours. In the afternoon on both days, there were spells of rain, contributing to a very irregular wind speed as shown in 14. During precipitation the evaporative water cooling of the conductors will generally compensate for possible lower convective wind cooling. For these situations a more realistic forecast can be produced by introducing more uncertainty in the wind speed forecast.



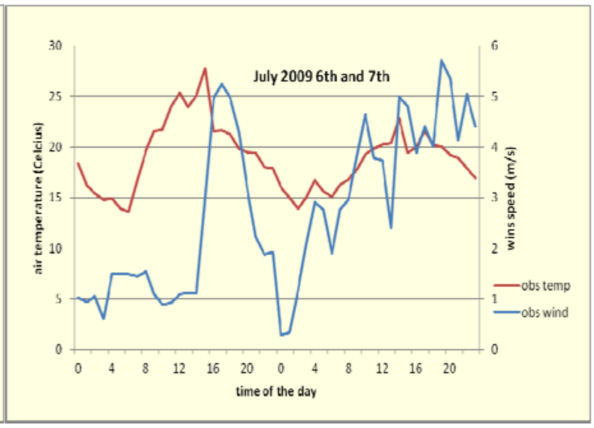
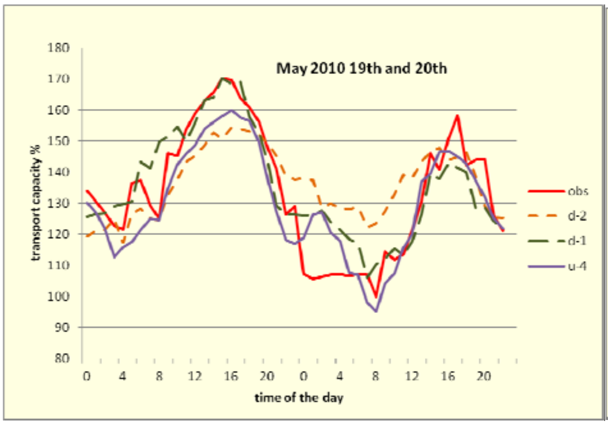


Figure 13 (left) Capacities on July 2009 6th an 7th.
Figure 14 (right) Observed wind and temperature in the critical span

Case 2

In a strong diurnal situation, the wind fell to almost zero from 0.00 hours to 07.00 o'clock, as shown in Figure 16. The lowest forecasts were around 1.4 m/s, the observed wind 0.3 m/s. Temperatures of about 3 to 4 ^{0}C below forecasted values could not compensate the reduced convective cooling. Figure 15 shows that the predictions in this case were too high between 0.00 and 07.00. A specific remedy for such type of error has not yet been developed.



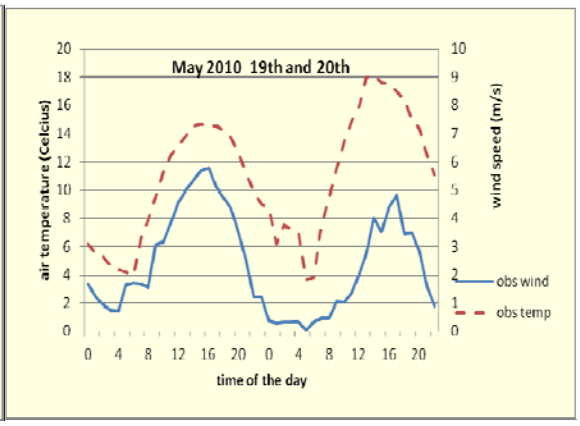


Figure 15 (left) Capacities on May 2010 19th and 20th
Figure 16 (right) Observed wind and temperature in the critical span

<u>Conclusions and future work</u>
The concept of weather forecasted dynamic rating is promising for application in the Netherlands. With hardly any hardware needed, it is possible to model all our 12500 towers and connect the predicted rating as needed to the programming and operating processes. Also intra-day programming can benefit from short term forecasting dynamic rating. For sections in the network where an economic trade-off can be made between increasing year-round capacity and a probability of last minute or last hour measures to avoid overload, weather forecasted dynamic rating allows maximization of profits.

The thermal capacity of the overhead conductor is not always the limiting factor for a line. Network stability, voltage limitations and the rating of other equipment in substations, like circuit breakers, may set limits. Capacities above 150% of the design capacity are treated with caution, for the time being these will be capped to a maximum of 150%. Also capacities under 100% should not lead to over reaction in situations where historically no capacity concerns were encountered. Maybe these should be capped to a minimum of 100%.

Further refinement is undertaken:

- Install real time monitoring to verify that calculations with this model are on the safe side
- A second pilot for a line with 90 towers currently runs where every hour the hourly capacity forecast is prepared looking 72 hours ahead and 6 hours back.
- First application in the Energy Management System (EMS) is envisaged for air temperature corrected ratings only, later to be followed by ratings also incorporating wind influences.
- The reliability of weather forecasted dynamic rating can be higher compared to the reliability level of a classical deterministic rating system in a hot summer night, but there is still scope for further improvement.
- Incorporate additional weather information, like radar information, in future model development, and improve forecasts during conditions of low wind speed. All aiming at further reduction of overestimations.

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