DYNAMIC CAPACITY RATING FOR WIND COOLED OVERHEAD LINES

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ABSTRACT

This paper shows that with presently applied static capacity rating for overhead lines there is a high unutilized capacity a large percentage of the time. The possibility for applying dynamic line rating in order to reduce or postpone reinforcements of overhead lines using weather measurements in the power line corridor and thus not causing delays for the wind power planners is assessed in this paper. Very few occasions of low wind cooling in the power line corridor at the same time as high wind at nacelle height have been observed.

INTRODUCTION

The overhead lines in the Swedish regional network threaten to become bottlenecks for the rapid increase of wind power installation. Vattenfall as a network owner with around 15000 km of overhead lines receives a large amount of requests for connection of smaller or larger wind farms to their grid. Load flow analysis will often show that one or more of the existing overhead lines will have overload during hours with high wind power generation. The capacity of the overhead line is limited by the temperature of the conductor and the corresponding sag. The capacity is a static parameter determined assuming worst-case weather conditions.

The possibility of applying dynamic line rating to reduce or postpone reinforcements of overhead lines using weather measurements in the power line corridor was assessed in this paper. Employing this supervision method secures that existing overhead lines shall not risk too high temperature. It will make possible to avoid delays in wind farm connection as reduced power can be ordered when required.

BACKGROUND

Challenges for the network

Vattenfall as well as most network owners today receive a large amount of requests for connection of smaller or larger wind farms to their grid. Load flow analysis will normally show that one or more of the existing overhead lines will have overload during hours with high wind power generation if the wind farm projects are realized.

Until 2005 Swedish wind power has primarily been a concern for the local networks. The requests for connecting wind power to regional networks have increased rapidly in the last years. In 2006 Vattenfall was asked to connect a few hundred MW wind power to their Swedish networks. Therefore, the meshed 40 - 130 kV regional networks and their capacity for wind power transmission are of vital importance. The overhead lines will become bottlenecks when large scale integration of wind power is implemented. The overhead line capacity calculation is based on the rather conservative assumption that the wind speed perpendicular to the conductor is only 0.6 m/s also at hours with high wind power generation.

It is shown that a small increase in wind speed above the assumed 0.6 m/s will increase the capacity of the line quite a lot. Vattenfall Nordic Distribution has therefore proposed to investigate if a higher wind speed perpendicular to the regional overhead lines can be accounted for in the calculation during hours with high wind power generation. This wind cooling would then allow a higher load on the overhead lines and favorably reduce the overhead line reinforcement requirements.

Transmission capacity

Overhead lines in a power system can have different limiting factors depending on their length and size. Voltage drops can limit long lines and annealing temperature can limit lines that are normally operated at high temperatures. The power lines that were studied in this project are such that they are limited by the regulations regarding ground clearance, i.e. the safety distance between the lowest point of the conductor and the ground.

Dynamic rating techniques

There are different rating techniques available on the market and new concepts are still developing. The algorithms used for dynamic rating are mostly based on the CIGRÉ [1] and the IEEE [2] methods. Many systems are sold as full-concept-solutions including software and with individual solutions for the buyer. The largest difference between products of different manufacturers is which parameters are measured and used as input in the calculations. Some systems rely on net temperature differences that include more than one weather parameter whereas some systems measure all weather parameters. Other differences are which parameter that is measured to represent the line temperature. The line temperature itself can be measured, at one point or as distributed, the tension or the position of the line or a technique based on vibrations can also be used to represent the line temperature. These different systems are at different development stages and some require physical operations on the line whereas some can be installed without taking the line out of service.

The technique of dynamic rating of overhead lines is not new. Weather stations have been used for this purpose more than 30 years whereas a vibration monitoring technique is less than three years old [3].

Towards full scale implementation

There are a number of steps to be taken before the full scale implementation of the dynamic capacity rating of the overhead lines. The paper describes:

- The weather studies based on statistical data
- The site measurements
- The set-up for the ongoing pilot installation.

If the pilot installation will show the successful results the concept is planed to be widely implemented on the region lines within Vattenfall Distribution Nordic.

WEATHER STUDIES

Best- and worst case scenarios

A modification of the static concept to fit wind power transmission seemed like a very attractive solution to the under-dimensioned regional network problem. This way, regional overhead lines in general would be granted a 'wind bonus' capacity. The size of this bonus would depend on the physical distance between wind power production and transmission line. To simplify, two cases were established:

1) In the best case scenario, the power line is directly under the wind power plant
2) In the worst case, coastal wind power feeds a distant inland power line.

The worst case correspond to how a scheduled wind power expansion at the Swedish west-coast, could affect the distant 130 kV overhead line.

How often are the coastal wind strong and the inland wind weak simultaneously?

The Swedish Meteorological and Hydrological Institute (SMHI) were consulted for a statistical study. Analyzing the worst case scenario, they would answer the question: 'How often are the coastal wind strong and the inland wind weak simultaneously?' A constraint was a high inland ambient temperature; so that only situations where insufficient cooling of the overhead line threatened would be considered. No specific wind power sites or overhead lines were studied. Instead, two coastal and two inland SMHI weather stations were employed.

Weather statistics from 1996-2007 were used with hourly mean values from the four weather stations. In 12 years only 30 hours were found, where coastal wind > 12 m/s coincided with inland wind < 2.5 m/s, together with an inland air temperature > 20°C. Thus, the conclusion was that these are rare situations historically.

Mapping power line 'hot-spots'

In order to study the distribution of the "hot-spots" and identify risk hours for insufficient cooling, the detailed weather conditions assessment along a specific 35 km overhead line was conducted. This time, the impact of insolation (e.g. cloudiness) was also considered. The specific 130 kV overhead line was chosen because it had been assessed a future bottleneck for wind power expansion. The study made use of computational fluid dynamics (CFD), simulating the air movements around the power line on an hourly basis over nine years. Again, historical weather data was used.

The calculations indicated 62 risk hours and 10 high risk hours for insufficient cooling over a period of 9 years. These results confirm that high risk hours are historically rare. They imply the possibility of some kind of wind bonus for overhead lines. Further, the successful mappings of hot-spots (clearly concentrated in densely forested areas) indicate the potential for heat monitoring of overhead lines. The capacity of the overhead lines would then depend on weather conditions in real-time. Dynamic rating of power lines would be possible, instead of the static one described above.

SITE MEASUREMENTS

Planning for measurements

The studies described in the previous sections were based on hourly mean values and historical weather data only. The next logical step was to perform measurements. This way, fast fluctuations in weather and current could be assessed. Hourly mean values could otherwise hide rapid overload situations. The mathematical relation between load, weather and elongation of the line could also be assessed. The measurement strategy was to fulfill these purposes:

1. Quantify the worst case scenario. That is, find the wind bonus for the regional network. Validate the historical rareness of high risk hours.
2. Quantify the best case scenario. That is, find the wind bonus for a local power line feeding a wind farm.
3. Collect measurement data to assess the mathematical relation between load, weather parameters and power line elongation.

Measurement system selection

There are several measurement systems on the market for power line measurements and the market was scanned to find the most suitable solution for the purpose of this research project.

Whereas there are many products on the market with different solutions for measuring dynamic rating-related parameters, the choice to measure ground distance directly narrows the field quite a lot.

Measurement results

Measurements of weather conditions in the power line corridor, line temperature and spatial position as well as wind speed at nacelle height were made for one year on two locations in southern Sweden. The sites were chosen as probable hot spots along the power line with good wind shielding.

Figure 1 shows quite typical measurement results from a summer day at the site. The line temperature increases rapidly during morning hours with increasing insolation. This figure is intended to give a feeling for the line temperature behavior.

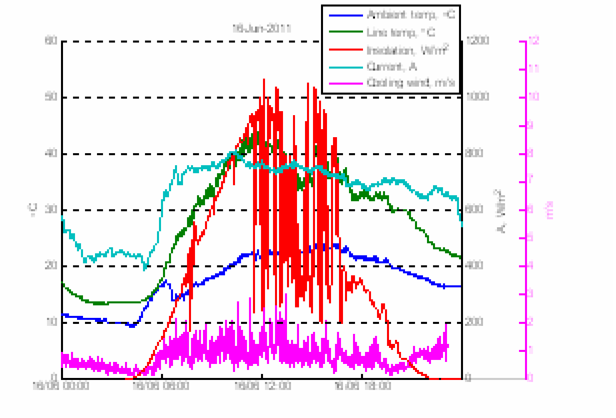

Figure 1 Examples of measurements on site. Note that the right axis shows the current scale and the left axis shows both temperature and ground distance

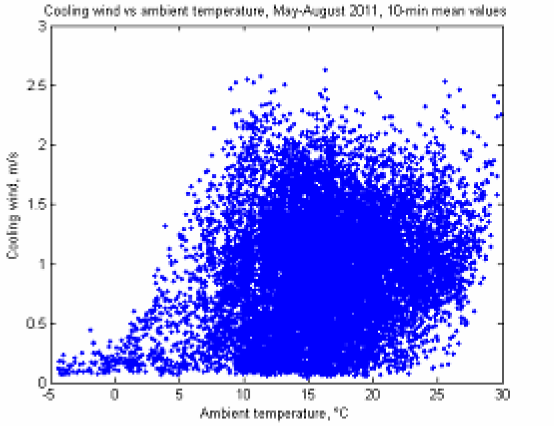

Figure 2 Correlation between the cooling wind and the ambient temperature.

Here it is obvious how some cloudiness in the afternoon decreases the line temperature from around 45 °C to 34 °C during otherwise fairly constant conditions.

Note that the wind speed ("cooling wind") in figure 1 is the wind perpendicular to the conductor.

In figure 2 we can see how the cooling wind correlated with the ambient temperature during the summer months May to August. We can see that low wind speeds dominate at low ambient temperature but that there also are occasions with low cooling wind at ambient temperatures over 25 °C although these occasions are very few.

From May to August 2011 31% of the observations of cooling wind was below the worst-case-scenario value of 0.6 m/s. These observations were more common during night time than day time. 0.4 % of the total number of observations showed an ambient temperature above 25 °C and a cooling wind of less than 0.6 m/s. 3.7 % showed an ambient temperature above 20 °C together with a cooling wind of less than 0.6 m/s.

Critical weather situations

During the measurement period of one year two occasions with a line temperature close to 50 °C (the thermal limit of the line) were observed (49.8 °C and 50.0 °C). The duration of these high line temperatures lasted however only a couple of minutes. Both days were very hot for Swedish climate with ambient temperatures of 28-30 °C. The measured current at this time was in one of the occasions above the rated value for the line (810 A).

Sag and line temperature correlation

During the warm summer period of May to July 2011 the ground distance varied with 2 meters for the measured span, when the line temperature varied with 54 degrees. There is a clear linear trend in the measured data when comparing line temperature to ground distance. It seems that for this span the ground distance can be estimated using a point value for the line temperature.

Wind speed at 100 meters height

The wind climate at 100 meters height is represented with a wind rose in figure 3 (left) and in the close by power line corridor (right). The wind direction in the latter is skewed to the direction of the corridor which means that most winds are parallel to the power line.

The wind speed measurement at 100 meters was compared to the cooling wind in the power line corridor, figure 3. The traditional assumption of 0.6 m/s is shown in the figure as a red line. We can see that at wind speeds reaching full wind power production (> 11 m/s) there are very few occasions with low wind cooling.

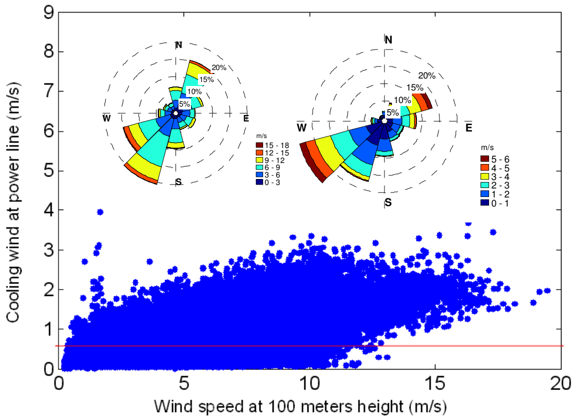

Figure 3 Cooling wind in power line corridor vs wind speed at 100 m height (red line is 0.6 m/s). Wind roses at 100 m and in the power line corridor.

POTENTIAL RATING

Figure 4 illustrates why the concept of using dynamic line rating is so attractive compared to just allowing higher static rating for wind power transmission. The figure illustrates that with traditional static rating there is a high unutilized capacity of the overhead line a large percentage of the time. It also illustrates that there are a few occasions of overestimation of line capacity using today's standard assumptions. Higher static rating will increase the risk of overestimated occasions considerably, while the dynamic rating will yield the optimal utilization of the assets.

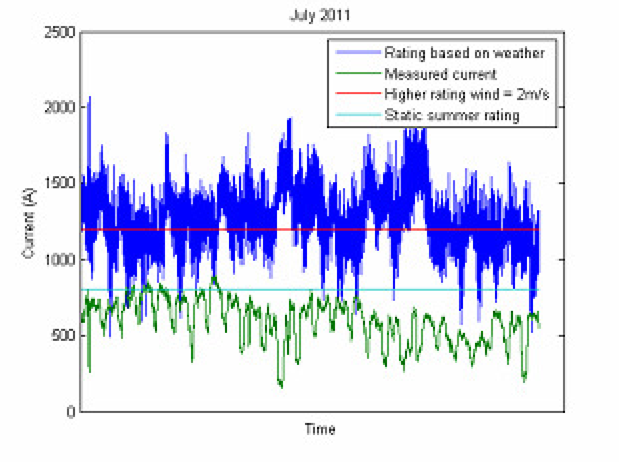

Figure 4 Comparison between dynamic line rating and static line ratings

PILOT INSTALLATION

The pilot installation were the concept of Dynamic Capacity rating will be implemented is ongoing. 40 kV regional overhead line has been chosen. The line already has a capacity problems due to wind power connected to the underlying low voltage networks.

The requirements and preferred functions for the equipment are summarised as following:

- Commercially available complete system including the possibility to integrate into the dispatch centre
- Calculations of the Dynamic Capacity rating as a part of the commercial package.
- Communication with the dispatch centre can be solved in a secure manner
- Function to measure of both temperature and the line sag
- Measurement of sag not only locally, but as an average including several line spans
- The weight of the equipment should be minimised.

The equipment called USi's Power Donut has been chosen. It has been installed in November 2012. The pilot is ongoing and the goal is to apply the dynamic capacity rating and in case of overload steer the wind power plants contributing to overload.

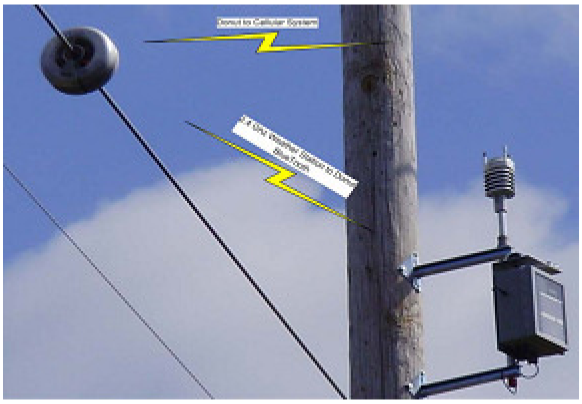

Figure 5 Pilot installationon of USi's Power Donut at the 40 kV line

CONCLUSIONS

The overhead lines in the Swedish regional network threaten to become bottlenecks for the rapid increase of wind power installation. Load flow analysis will often show that one or more of the existing overhead lines will have overload during hours with high wind power generation. The capacity of the overhead line is limited by the temperature of the conductor and the corresponding sag. The capacity is a static parameter determined assuming worst-case weather conditions.

The possibility of applying dynamic line rating to reduce or postpone reinforcements of overhead lines using weather measurements in the power line corridor was assessed in this paper. Employing this method could avoid causing delays for the wind power planners caused by under dimensioned overhead lines. Measurements of weather conditions in the power line corridor, line temperature and spatial position as well as wind speed at nacelle height were made for one year on two locations in southern Sweden. The sites were chosen as probable hot spots along the power line with good wind shielding. The results show a high unutilized capacity of the overhead line a large percentage of the time but also a small percentage of overestimation of line capacity using today's standard assumptions. Very few occasions of low wind cooling in the power line corridor at the same time as high wind at nacelle height have been observed.

REFERENCES

[1] CIGRÉ, (2002). *Thermal behaviour of overhead conductors*

[2] IEEE, (2006). *IEEE Standard for calculating the current-temperature of bare overhead conductors*

[3] CIGRÉ, (2010). *Increasing capacity of overhead transmission lines – Needs and solutions*

[4] *E. Lindberg, A. Bergström, U. Axelsson, P. Söderström, V. Neimane, T. Johansson, P. Schelander,* "Dynamic capacity rating for wind cooled overhead lines", NORDAC, Espoo, Finland, September 10-11, 2012.