FIELD MEASUREMENTS ANALYSIS FOR DYNAMIC LINE RATING

Martin ATEN
E.ON New Build & Technology – UK
Martin.aten@eon.com

Robert FERRIS
Central Networks – UK
Robert.ferris@central-networks.co.uk

Tony YIP
Alstom Grid - UK
Tony.yip@alstom.com

Chang AN
Alstom Grid – UK
Chang.an@alstom.com

Graeme Lloyd
Alstom Grid – UK
Graeme.lloyd@alstom.com

ABSTRACT

Central Networks has implemented a scheme to calculate the rating of the Skegness-Boston 132 kV line dynamically in their control system from local weather measurements thereby enabling a larger penetration of wind generation. The paper describes the analysis of field measurements collected over four seasons for the dynamic line rating scheme. The concept of using weather measurements and CIGRE 207 equations is evaluated by comparison of calculated conductor temperature with measurement of the same using a sensor connected on the conductor. The dynamically calculated ampacities at Skegness and Boston are also analysed and comparison is made with the standard line rating used conventionally.

1 INTRODUCTION

Future electricity networks will have to accommodate large scale distributed generation with renewable energy resources such as wind farms. One of the problems facing the electricity utilities is the thermal ratings of the networks. Whereas distribution networks were designed in the past to distribute power to consumers from centralised power stations connected via the transmission grid, now they have to accommodate additional in-feeds from distributed generation. The network operators are under pressure to utilise their network resources to the fullest to accommodate such distributed generation.

An earlier CIRED paper has described application of dynamic line rating for the Skegness-Boston double circuit 132 kV line [1]. Central Networks have proposed to calculate the rating of the line dynamically in their control system (ENMAC) from local weather measurements to co-ordinate allowed generation automatically. Due to the cooling effect of the wind, it is expected that such a dynamic line rating enhancement can facilitate connection of up to 30% or more generation as compared to when fixed winter/summer ratings of 539A / 433A (LYNX conductors ER P27 [2]) are applied. As a back-up system, in case for some reason the wind farm power output is not reduced on command by the control system, a relay will initiate tripping of the wind generators.

This paper describes the results and analysis of field measurements that have subsequently been collected over four seasons.

2 CONDUCTOR TEMPERATURE ANALYSIS

The CIGRE 207 standard equations have been chosen [3] to derive ampacity from weather measurements. Since ampacity cannot be measured directly, the accuracy of the proposed method is evaluated by using the weather measurements and CIGRE 207 equations to calculate the conductor temperature, which is compared with the conductor temperature measured by the power donut™ (a sensor clamped on a line conductor). The derived conductor temperature is an iterative calculation based on the measurements of ambient temperature, wind speed, wind angle, solar radiation and line current.

Data over four seasons has been captured. Unfortunately, it has not been possible to capture valid measurements consistently throughout the trial period, because of lack of power supply to the Power Donut™ temperature sensors, which is dependent on the line current and a limited internal battery capacity. The current through the Skegness-Boston line is very variable with many dips to near zero due to the wind generation offsetting the local load.

Figure 1 shows the impact of weather conditions and current on the conductor temperature, using 1 minute samples with 10 minute rolling average of all data for an autumn day. Figure 2 shows the same for 30 minute average samples (1 minute samples averaged out over 30 minutes). A total of 159 hours (6.6 days) worth of reliable data spread over four seasons was analysed in a similar way. There is generally a good correlation between the measured conductor temperature and as calculated from the Cigre calculations for both time resolutions, but the accuracy is somewhat compromised for the 30 minute average samples.

The curves labelled as 'Tconductor CIGRE conservative' represent the conductor temperature calculated using the conservative assumptions mentioned in [1]:

1) The wind speed measurement is multiplied by a fixed wind angle factor of sin (20°) = 0.34 to take into account wind angle. Actual wind angle is difficult to take into account, because (i) the line changes in direction from Skegness to Boston and (ii) wind direction can be quite variable. It is assumed that if the actual wind angle is less than 20°

to the line, the cooling effect due to wind turbulence is roughly as high as assuming that there is no turbulence but assuming 20° wind angle.

2) A fixed solar radiation of 890 W/m^2 is adopted. This conservative approach is taken because it is very difficult to take into account actual solar radiation along the line due to the fact that the presence of clouds above the line can vary significantly locally.

The calculated conductor temperature with these conservative assumptions is most often well above the measured conductor temperature by a range of 3.4°C to 11.1°C. The difference is smaller whenever the solar radiation is high and wind angle near zero.

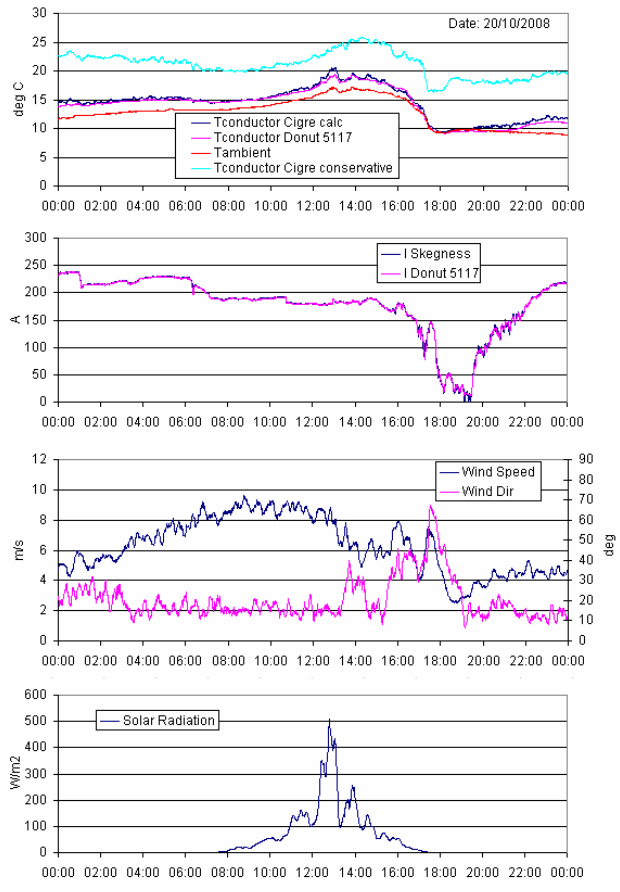

Figure 1: Conductor Temperature CIGRE 207 Calculation Results and Field Measurements taken on 20/10/08 (Autumn), 10 min Rolling Average, 1 min Samples

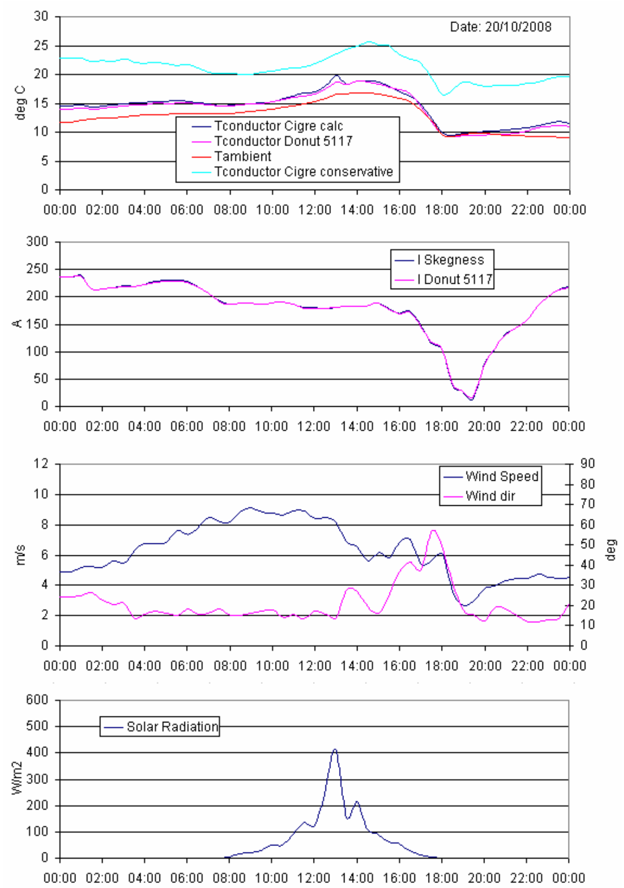

Figure 2: Conductor Temperature Cigre 207 Calculation Results and Field Measurements taken on 20/10/08 (Autumn), 30 min Average Samples

From Figure 1 and similar figures for other periods not presented here, it can be observed that the effect of high frequency fluctuations in weather measurements and current are smoothed out in the measured conductor temperature. This is due to the thermal time constant of the conductor which is in the order of 10 to 25 minutes [3].

Figure 3 shows the frequency distribution of the difference between the calculated conductor temperature and the one measured by the Power Donut^{TM}. Whereas the Power Donut^{TM} measurement is based on one minute samples in both cases, the calculated values are given for 1 minute samples with 10 minute rolling average, and 30 minute average samples as input values. The histograms reveal that with 1 minute samples, the discrepancy is between -2 to 2°C for 99.4% of the time, and between -1 to 1°C for 88.3% of the time. If 30 minute samples are used then the discrepancy is between -2 to 2°C for 97.2% of the time, and between -1 to 1°C for 86.5% of the time. This illustrates the typical accuracy of the CIGRE equations with the weather measurements as input.

As expected, the accuracy is slightly reduced by using half hourly as opposed to one minute weather samples for the calculations. The accuracy is however still adequate when considering the margin between the conductor temperature measured and calculated with the conservative assumptions on wind angle and solar radiation. Whereas a higher resolution gives obviously a better accuracy, this is at the expense of a higher burden on data processing.

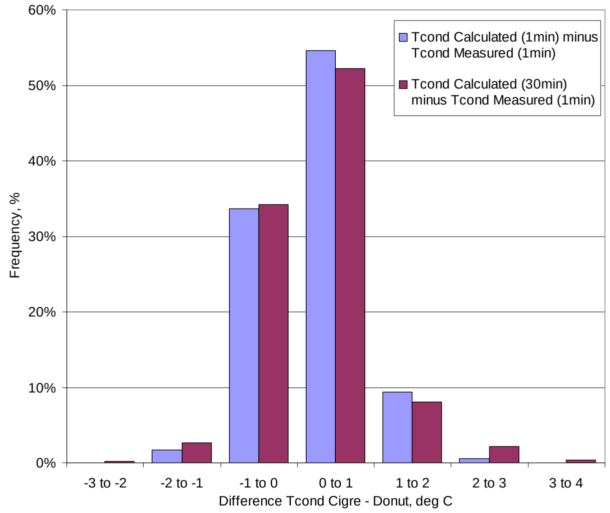

Figure 3: Frequency of Difference between calculated and measured conductor temperature. Discrepancies are given using 1 min Samples (10 min Rolling Average) and 30 min Average Samples for the calculations.

3 AMPACITY ANALYSIS

Figure 4 shows the calculated ampacities at Skegness and Boston, the Skegness-Boston line current, and weather measurements over a week in winter using 1 minute samples with 10 minute rolling average. A total of 696 hours (29 days) worth of data spread over four seasons has been analysed. The P27 static winter rating for Lynx conductor is 539A.

The theoretical ampacities use the actual measured wind angle and solar radiation measurements, and the conservative ampacities are based on the assumptions made on fixed wind angle (20°) and solar radiation (890 W/m^2) mentioned earlier. The conservative ampacity is used for practical operation, and analysis over four seasons reveals that this creates ample margin with the theoretical ampacity most of the time. The margin gets lower when the wind angle is less than 20° and solar radiation is high, but this happens only sporadically and for very short durations.

The load management system receives weather information from both Skegness and Boston, whereas the relay just receives weather information from Skegness. For the purpose of achieving adequate margin between control and protection operation, there are two options for the ampacity to be used for the load management system:

1) Use the "worst weather" conditions, which is the highest temperature and lowest wind from Skegness and Boston, to calculate the ampacity applied to the line.

2) Take the minimum of the ampacities calculated from weather conditions at Skegness and Boston.

Option 1 will give either an identical or lower ampacity than Option 2. From analysis carried out over a total of 696 hours (29 days) worth of data spread over four seasons, it appears that both options give for most of the time identical ampacities, and their difference is very small when they do differ.

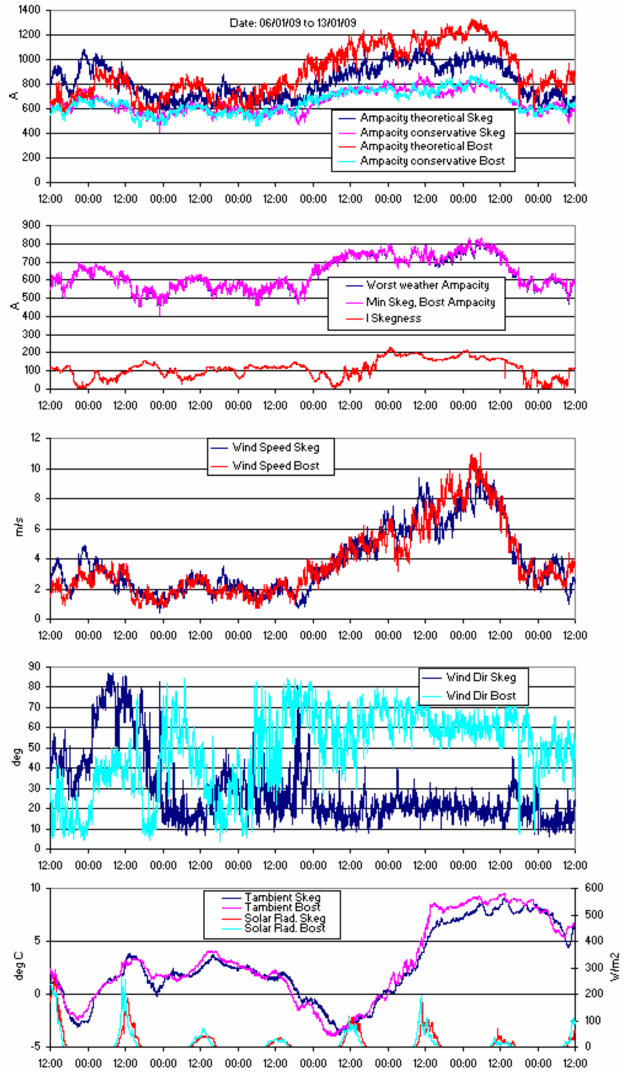

Figure 4: Ampacities from Cigre 207 Calculation Results and Field Measurements taken from 06/01/09 to 13/01/09 (Winter), 10 min rolling average, 1 min samples

It is currently proposed that the load management system uses the "worst weather" conditions to derive the ampacity. A desirable margin between the load management system and the relay is provided by the fact that the worst weather ampacity used for load management is most of the time lower than the Skegness ampacity used for the relay, thus allowing control action to take place before trip action.

However, load management and protection also need to be coordinated to ensure that the relay would adequately protect against thermal overloading in the unlikely scenario that the theoretical (taking into account wind angle and solar radiation) Boston ampacity is lower than the Skegness conservative ampacity.

From the analysis, it appears that the conservative Skegness ampacity is often higher than the conservative Boston ampacity. This may be explained by a somewhat higher average wind and slightly lower average temperature at Skegness compared with Boston. Figure 5 shows the frequency distribution of the conservative ampacity at Skegness subtracted from the one at Boston. From the corresponding data it is calculated that for 71.2% of the time the ampacity at Skegness is higher than that at Boston, and for 19.8% of the time this difference is higher than 10%.

For the majority of time however the conservative Skegness ampacity is lower than the theoretical Boston ampacity: for the four seasons analysed, the Skegness ampacity (used by the relay) is equal or lower than the Boston theoretical ampacity for 96.3% of the time over the four seasons analysed. By introducing a margin of no less than 5% between the line current at which load management will be initiated and the wind farm trip setting, the relay at Skegness would provide adequate protection against a thermal overload at Boston for at least 99% of the time, if the load management system failed. Note that this particular result is not universally valid and will be site specific. An alternative solution could be to provide the relay at Skegness with weather information from Boston as well, however this introduces the drawback of the protection relying on a telecommunication system.

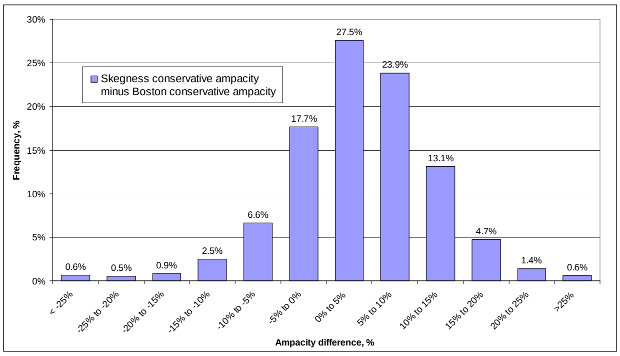

Figure 5: Frequency of Difference between Skegness Conservative Ampacity (Relay) and Boston Conservative Ampacity

Finally, Figure 6 shows by how much the dynamic conservative ampacity at Skegness differed from the Standard P27 rating in 2009. The dynamically calculated ampacity is above the P27 standard winter and summer ampacities for about 90% of the time.

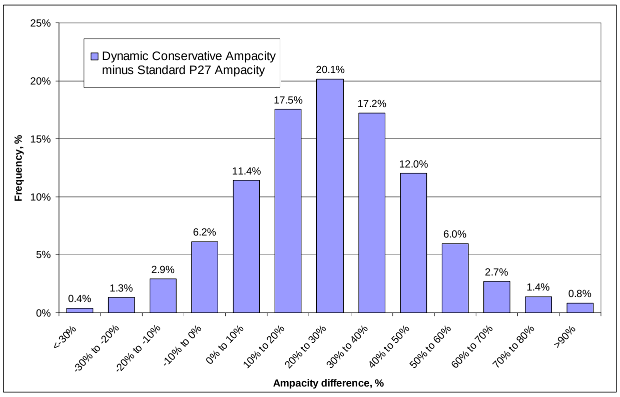

Figure 6: Frequency of Difference between Dynamic Conservative Ampacity at Skegness and Standard P27 ampacity, for 2009

4 CONCLUSIONS

This report describes the results and analysis of field measurements collected over a year for the dynamic line rating scheme comprising load management and protection of the Boston-Skegness line. The concept of using weather measurements and CIGRE 207 equations is evaluated by comparison of calculated conductor temperature with measurement of the same using a sensor connected on the conductor. Analysis was carried out using 1 minute and 30 minute sampled weather data. Although 1 minute sampled weather data provides the highest accuracy, using 10 to 15 minute samples could reduce the burden on data processing while accuracy is still adequate, due to the thermal time constant of the conductor which is in the order of 10 to 25 minutes.

Analysis of the dynamically calculated ampacities over four seasons reveals that there can be significant difference in ampacity at Skegness and Boston (40km apart) due to local weather conditions. This needs to be taken into account for coordination between the load management and protection relay if the latter only receives local weather data.

The ampacity analysis also shows that compared to the static ratings dynamic line ratings can enable up to 30% or more wind generation to be connected to the grid by taking into account the weather parameters.

REFERENCES

[1] T. Yip, M. Aten, B. Ferris, G Lloyd, C An, 8-11 June 2009, "Dynamic line rating protection for wind farm connections", *CIRED 20th International Conference on Electricity Distribution*, Paper 0733.

[2] Electricity Association, "Engineering Recommendation P27; Current Rating Guide for High Voltage Overhead Lines Operating in the UK Distribution System", 1986.

[3] CIGRE Technical Brochure Ref. 207, August 2002, *Thermal Behaviour of Overhead Conductors*, Working Group 22.12.