USE OF REAL TIME THERMAL RATINGS TO SUPPORT CUSTOMERS UNDER FAULTED NETWORK CONDITIONS

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ABSTRACT

As electricity demand grows, there will be an increasing number of locations where circuits designed with 100% redundancy will no longer be adequate, and following the failure of a single supply circuit the remaining circuit would be in danger of exceeding its static thermal rating at times of peak demand. In the longer term, expensive network reinforcement would be required to avoid breaching national security of supply standards.

A lower cost solution than network reinforcement could be to increase the thermal rating of the remaining circuit. Use of real time thermal ratings (RTTR) can increase the static rating of a critical circuit to a generally higher dynamic rating, and thereby decrease the likelihood of customer disconnection, in particular at peak periods This paper considers a case study based on an actual section of network in the North of England, and on real time weather data. The potential of RTTR for mitigating the consequences of (n-1) failure is described and analyzed, including how it could be implemented in the control room.

INTRODUCTION

The use of Real Time Thermal Ratings (RTTR) to enhance the performance of network components is well documented. Increased power flow capability as a result of thermal modeling, using real meteorological data inputs allows the deferral and in some cases can negate the need for high-cost network reinforcement. Studies of this kind usually assume that the network is intact with no planned outages or faults on the system.

However, RTTR can also bring benefits on occasions when the network is disrupted. An earlier study described and evaluated these benefits in the case of (n-2) outages where two or more circuits are disconnected [1]. The present paper investigates the potential use of RTTR in the less serious, but more likely case of (n-1) outages. It is illustrated by a case-study which draws on the Customer Led Network Revolution (CLNR) a project set up to trial low-carbon technology on a distribution network in the North of England [2].

Real Time Thermal Ratings

Previous work has shown that RTTR can aid the contribution of Distributed Generation (DG) such as wind farms, by minimizing the need for curtailment [3]. If an Active Network Management (ANM) scheme using RTTR were to be installed, an increased capacity of DG could be connected. One issue which arises with the introduction of such a system is that the potential benefit is often seen solely by the DG owner and operator, while much of the resultant cost and risk lies with the Distribution Network Operator (DNO). Given the well documented benefits which an RTTR system can provide, the incentivizing of DNOs to deploy such a system will be integral to maximizing the potential of smart grids. The scheme outlined in this paper aims to provide a methodology to allow DNOs to gain benefit from the installation.

Whilst much work has been in consideration of the benefits for generation, an RTTR system can also provide robustness against future load growth; because additional load can be accommodated without the need for high-cost reinforcement.

A series of international standards detail the three main architectures for derivation of a conductor's maximum ampacity: the IEC [4], CIGRE [5] and IEEE [6] models. Work at Durham University (DU) has sought to combine the methodologies of the IEC and CIGRE models, using the wind direction corrective function in the latter [7]. For the purposes of this work, the CIGRE model has been used without alteration. The calculation of an overhead line's real-time maximum ampacity can be carried out by solution of the conductor's heat balance equation, as described in detail in [1].

In order to solve the heat balance equation, various meteorological parameters must be measured; wind speed (m/s), wind direction incident to the conductor (^{O}), ambient temperature (^{O}C) and solar radiation (W/m^{2}). With knowledge of the conductor's maximum operating temperature (for the OHL under investigation as part of this study the value is set at 50^{O}C) the heat balance equation can be solved to give a maximum steady-state current based on the incident weather conditions.

Network Risk

The UK standard for network risk is P2/6, which has been endorsed by the industry regulator OFGEM [8]. It specifies for different load sizes the maximum permissible customer disconnection times. One consequence of this standard is that, at voltages of 33 kV and above, duplicate supply circuits are the norm, where the loss of a single circuit will generally not disconnect customers.

However, over the next decade, peak loads are expected to increase significantly as a consequence of the take-up of electric vehicles and domestic heat pumps. At an increasing number of locations, circuits designed with 100% redundancy will no longer be adequate, and following the failure of a single supply circuit the remaining circuit would be in danger of exceeding its static thermal rating at times of peak demand. This could result in the disconnection of a number of customers, at a cost to the DNO measured by the regulatory penalty imposed for customer interruptions (CI) and customer minutes lost (CML). Earlier work has used a methodology where the expected value of this penalty can be calculated [9]. In the longer term, a large amount of expensive network reinforcement would eventually be required to avoid breaching national security of supply standards, and the year in which such reinforcement would be needed can also be predicted [10].

If the thermal ratings [11] can be increased with confidence, however, the proportion of customers supplied during a (n-1) fault event can also be increased. This can be achieved by the smart deployment of an RTTR system. The way in which this could be achieved is illustrated by the case study which is now described, based on an actual network in the North of England where increasing loads , in particular at peak times, are likely to lead to a shortfall in capacity by the end of the decade.

CASE STUDY

Primary substations 'A' and 'B' together serve over 16000 customers in the North of England, with a present peak demand of over 34 MW. They are supplied by two independent teed 33 kV circuits as shown in Figure 1. These supply circuits each consist of underground cable for the first 2.9 km, followed by 1.6 km of overhead line to the tee. These sections of overhead line are the most critical as regards static ratings.

In the event of a fault on one of the two circuits, the remaining circuit would be required to carry the full load to both primaries. The critical section of both circuits is 175 mm^2 ACSR overhead line, with static ratings defined as 30.8 MVA (winter), 28.6 MVA (spring/autumn) and 24.7 MVA (summer) [11]. Analysis of actual half hourly load data for the 12 months from August 2011 to July 2012 indicates that the summation of load at both primaries reached peak values in excess of the single circuit static rating on several occasions during all four seasons, indicating that the use of RTTR could be of potential benefit throughout the year.

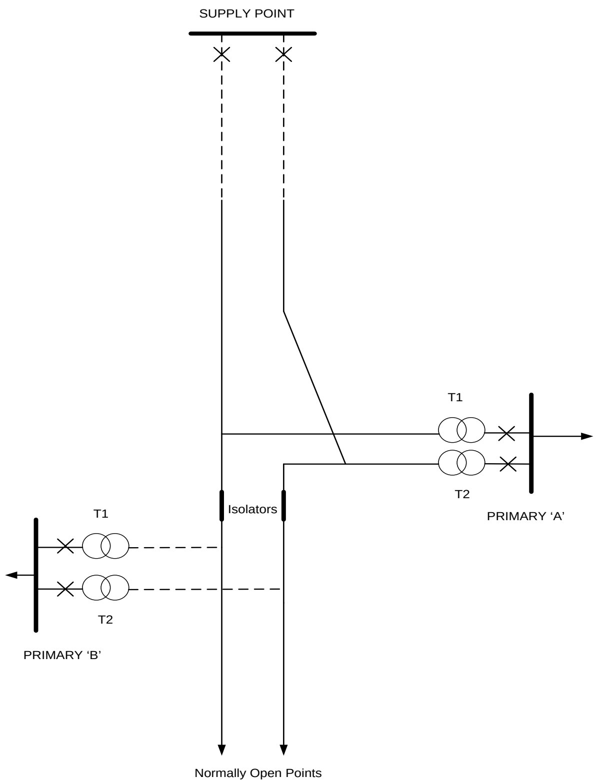

Figure 1 – Schematic of supply circuits

Estimating the shortfall

Detailed analysis of the half hourly load data has been carried out for the 5 month period from March-July 2012. This period has been chosen to correspond to the period for which actual weather monitoring has been in place, and therefore RTTR estimates can be made.

Allowance must be made for losses. Estimates of losses between the critical sections of overhead line, and the 11 kV side of the transformers at both primaries are around 0.95% with the network intact. Since losses are generally proportional to the square of the current in any circuit, with the network operating in (n-1) mode overall losses double, to 1.9%. This must be added to the 11 kV loads to estimate the power that would need to be carried by the single remaining circuit following an (n-1) single circuit loss.

It is also assumed that demand in any half hour throughout the year increases at an annual linear 0.5%, leading to an increase of 3.5% for 2018-19 as compared with the recorded value for the same half hour in 2011-12. The effectiveness of a RTTR solution is then calculated for expected 2018-19 loads.

On this basis, the potential shortfall at any time can be assessed, and Table 1 shows the results for each of the 5 months under consideration. It is significant that the lower summer rating leads to a significant increase (in May and in July) not only in the number of days when shortfall is experienced, but also in the average duration of each day's shortfall in hours, and in the maximum size of the power shortfall measured in MVA.

Month	*Static rating (MVA)*	*Days with shortfall*	*Average hours per day*	*Maximum shortfall (MVA)*
March	28.6	6	1.7	2.14
April	28.6	5	3.0	2.22
May	24.7	16	7.8	4.47
June	24.7	5	1.5	1.14
July	24.7	21	8.9	3.86

Table 1 – monthly variation in shortfall

IMPLEMENTING RTTR

The input to the CIGRE model used to calculate RTTR values is based on the actual conductor at the case study site (175 mm^2 ACSR Lynx, at 33 kV, strung to a temperature limit of 50°C), and on actual hourly weather data from the CLNR test site. This data is considered to be similar to that which could have been obtained by equivalent monitoring at the case study location, and can therefore still usefully be used to illustrate the proposed methodology.

RTTR Uplift

Actual hourly wind speed and temperature data from 4 weather monitoring sites in different locations (some more sheltered than others) is averaged. Solar radiation is assumed to be zero, and wind direction at 12.5° to the line of the conductor. On this basis, the RTTR is calculated each hour using the CIGRE model. The results are shown in Figures 2 and 3. Figure 2 shows how the monthly average RTTR (and average gain over static rating) depends on the monthly average ambient temperature and wind speed. In particular, March 2012 was both windier and warmer than April, and these two effects tend to offset one another, resulting in an almost equal average RTTR. The effect of the large step change on 1 May from spring to summer static ratings is also apparent, with May showing the greatest average potential gain of 30%. It is also of interest that relatively low wind speeds of around 2 m/s still give a substantial increase over static ratings (which are based on a wind speed of 0.5 m/s).

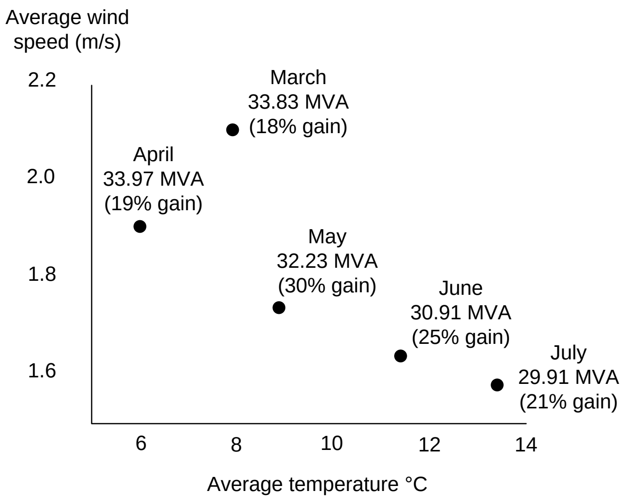

Figure 2 – Monthly average RTTR and potential gain

Figure 3 shows cumulative frequencies of individual hourly RTTR calculations, both in spring and in summer. Only on a few occasions is the RTTR lower than the static rating (11% in spring, 1% in summer). Usually there is an uplift of at least 10% of static rating (60% of the time in spring, 78% in summer). In the most extreme case (wind speed 8 m/s, temperature 7°) the calculated RTTR is 52.4 MVA, almost double the static rating.

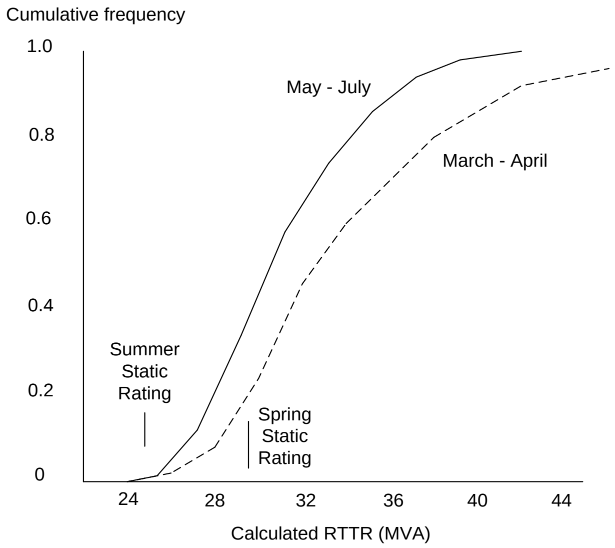

Figure 3 – cumulative frequencies of calculated RTTR

Application to Case Study

Table 1 shows that by 2019, if static line ratings are used, there are 53 days during the 5 month test period when, in the event of the loss of a single circuit at or around peak demand time, it would not be possible to supply all the 16000 customers of the two primary substations. Some of them would have to be deliberately disconnected, leading to financial penalties for the DNO in the short term, and a requirement to invest in reinforcement in the longer term.

Using RTTR, a different pattern emerges. A simulation was carried out to compare the power required to pass the critical point of the single remaining circuit with the RTTR on a half hourly basis throughout the 5 month test period. At each half hour, the power required (based on 2012 loads incremented by 3.5% for annual load growth and by 1.9% for losses) was compared with the calculated RTTR (based on test site data). On only 28 half hour periods out of 7296 (less than 0.4% of the time) was there still a shortfall. All the rest of the time, RTTR was greater than the power flow required.

Operational Considerations

Installing a RTTR system on the case study network would first require the placing of one or more weather monitoring stations near the most critical section of the two 33 kV overhead lines from the Supply Point to the tee. A model similar to the CIGRE model used in the present paper would then calculate the dynamic line rating, and the operations control system would then compare this with the load, generating an alarm if the load was close to or in excess of the dynamic rating.

As an example, the actual weather and load data from 17 July 2012, when it is applied to 17 July 2019, suggests that even using RTTR there would be a shortfall of 1.76 MVA (about 7%) for one hour around 1600, and another shortfall of 1.26 MVA (5%) around 1900. If a fault occurred during the first period, it would probably be necessary to disconnect one feeder (around 2000 customers) to prevent the conductor exceeding the 50°C design limit. However, it should be possible within an hour at most (less in the case of automated switching) to reconfigure the network so that the disconnected feeder could be fed from the far end, via a different primary substation. By the time of the second shortfall, this reconfiguration would have eliminated the need for any further customer disconnection.

CONCLUSIONS

Electrical loads are expected to increase over the next decade as a consequence of the growing electrification of transport and of domestic heating. There will be a consequent need for network reinforcement, preferably without high levels of capital expenditure. Smart grid technologies, including real time thermal rating (RTTR) could provide such a solution.

This paper looks at a RTTR solution applied to an actual case study located in the North of England. Based on actual weather data for 2012, it makes predictions for a simulated 5 month period in 2019. It estimates the number of hours during which thermal ratings would be exceeded in the event of a (n-1) fault on a double circuit supply, and concludes that this number could be reduced from 472 to 28 if RTTR were used in place of static ratings. This result suggests that the use of RTTR could be a viable alternative method of uprating the overloaded circuits, as compared with costly capital expenditure on network reinforcement.

This case study is typical of many locations on distribution networks where load growth would eventually lead to the infringement of static ratings in the event of an (n-1) fault. The use of RTTR, typically in combination with other smart grid technologies including network automation, or demand side participation, has the potential to uprate the networks at an affordable cost.

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