DYNAMIC THERMAL RATING SYSTEM RELIEVES TRANSMISSION CONSTRAINT

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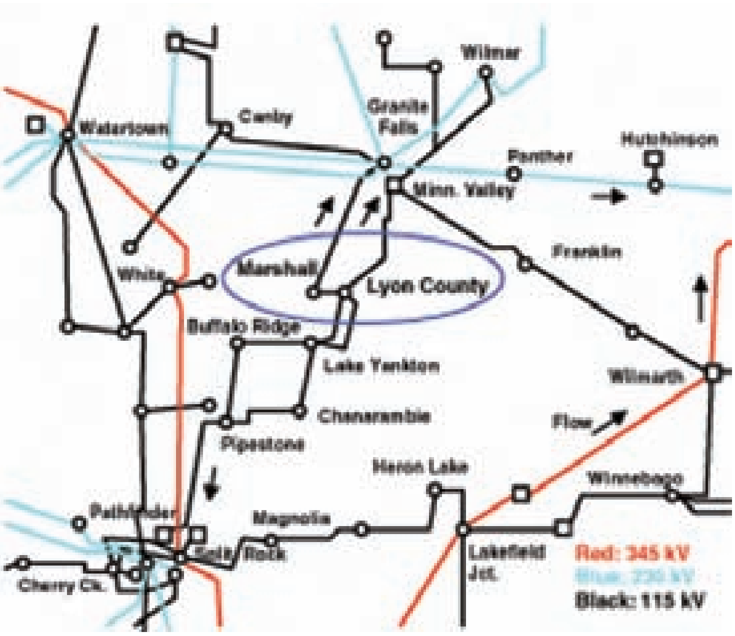

Figure 1 – System Map

Dynamic thermal line rating can optimize transmission operation by capturing previously unutilized line capacity while simultaneously improving system reliability. This article will introduce a new system for dynamically determining the thermal rating of an overhead line. The article will focus on a case study by describing how the system was used to relieve a transmission line constraint for a wind farm in the mid-western United States. A description of the particular constraint will be presented, followed by a discussion of the installation of the dynamic rating system and the integration of the dynamic rating data into operations. Results from the first summer of operation of the system will also be presented.

I. NOMENCLATURE

Thermal rating – the maximum current or MVA that can be transferred over a transmission line without exceeding the specified maximum operating temperature of that line.

Static rating – the thermal rating of a line as determined by assumed weather conditions. A line may have multiple static ratings (e.g. summer, winter).

Dynamic rating – the thermal rating of a line that is determined in real-time using actual weather conditions.

Transmission line constraint – a situation where a line transfer is limited by either normal system flow or post-contingent flow (flow that would result if a failure occurred somewhere in the system) exceeding the rating of the line.

II. SUMMARY

According to the American Wind Energy Association (AWEA), wind generation is the fastest growing energy source in the United States, with 2500 MW installed in 2005 and another 3000 MW expected in 2006. The rapid growth of wind generation and its location many miles from the large load centers have created significant challenges to the transmission providers. These challenges require innovative solutions, since it is not always possible, or cost-effective, to build new, or upgrade existing, transmission lines in time to provide outlet for the wind generation.

Xcel Energy learned this first-hand in 2005 when the wind generation growth in Southwestern Minnesota's Buffalo Ridge area was straining transmission outlet capacity. Xcel Energy needed to quickly increase the outlet capability of one of the lines leaving the area, or be forced to curtail wind generation. The line could not be taken out of service to be rebuilt because of reliability issues, and there was not enough time to construct a new line, so Xcel Energy and Marshall Municipal Utilities, the owner of the line, chose to dynamically rate it. Their choice of equipment was Shaw Energy Delivery Services' (EDS) dynamic line rating solution, the ThermalRate System.

The ThermalRate System was chosen because of the many advantages it offers over other dynamic line rating equipment. The major advantage is it does not need to be physically connected to the line, which simplifies installation and maintenance.

Since its commissioning in June 2005, the ThermalRate System has allowed Xcel Energy and Marshall Municipal Utilities to increase the LYC-MSH line rating and recognize previously unused capacity. The recognition of this capacity has allowed higher steady state and post-contingent flows and eliminated the need to curtail Buffalo Ridge wind generation.

III. BACKGROUND

Buffalo Ridge runs along the border between Southwestern Minnesota and Eastern South Dakota and is an ideal location for wind power generation because of the area's strong, steady

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transmission constraint

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winds. Wind generation development at Buffalo Ridge has grown dramatically during the last 10 years and now includes over 600 wind turbines capable of generating over 500 MW.

Xcel Energy completed a number of transmission upgrades at Buffalo Ridge in late 2004 designed to allow an additional 165 MW of wind generation. Upon completion, Buffalo Ridge had three 115kV interconnections to the 230kV and 345kV bulk transmission system; Lyon County – Marshall (LYC-MSH), Lyon County – Minnesota Valley (LYC-MNV) and Pathfinder – Split Rock (PAF-SPK) – See Figure 1.

During construction, it was determined that during times of high wind generation output, the LYC-MSH line could exceed its summer rating following certain transmission contingencies – which is not allowed. Unless the LYC-MSH line rating were increased, Buffalo Ridge wind generation would have to be curtailed beginning in May of 2005, when summer ratings take effect.

Rebuilding the LYC-MSH line was not a good option, since there are only two sources feeding the city of Marshall and the risk of taking one out for a long period of time was considered too great. Similarly, building a new line was also not considered a good option, due to the cost and time needed to complete the process.

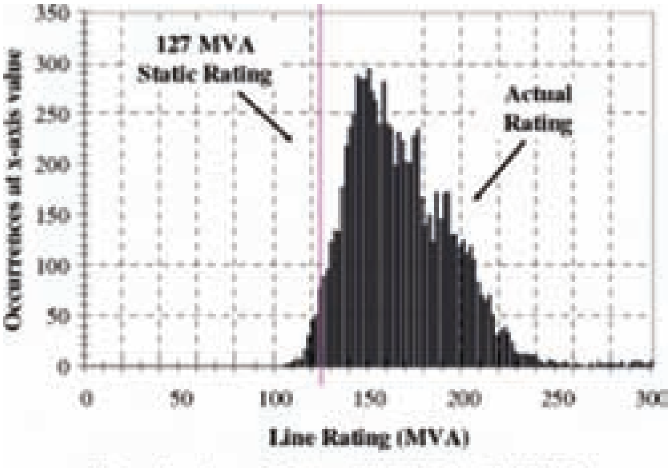

Figure 2 – Actual Ratings, 7/17/2005 to 8/17/2005

The post-contingent loading on LYC-MSH is only a concern during periods of high Buffalo Ridge wind generation. Marshall is located near the ridge, and historical weather data showed a consistent wind pattern between the ridge and Marshall. The actual wind effect on the LYC-MSH conductor was likely greater than was assumed when calculating the 127 MVA static summer rating for the line.

Xcel Energy and Marshall Municipal Utilities made the decision to dynamically rate the LYC-MSH line and identified the ThermalRate System as the best solution. The ThermalRate System was preferred because of (1) ease of installation, since the line did not need to be taken out of service; (2) simplified maintenance, since it is not attached to the line; and (3) accuracy, since it simulates the actual condition of the conductor.

IV. THERMAL RATING

The thermal rating of an overhead transmission line is the maximum current that the line can transfer without overheating. The line rating is a function of the weather conditions seen along the line, including wind speed, wind direction, air temperature, sun, and other secondary influences such as precipitation and indirect solar radiation.

The thermal rating of most lines is calculated based on sag.

As electrical current increases through an overhead conductor, the temperature increases, the conductor elongates, and the line sags. The thermal rating is the maximum current that can be transferred on the line without causing the line to sag past the minimum clearance to ground.

The sag, and therefore the thermal rating, is a function of weather conditions which, in most cases, are conservatively chosen using industry guidelines. Common weather assumptions are full sun, 40 Celsius (104 Fahrenheit) air temperature, and 2 ft/s (1.4 mph) wind speed perpendicular to the conductor.

Conservative assumptions must be used for safety reasons, but experience shows the actual line rating is usually much higher than the static rating. Therefore, using

a static rating can underutilize a line's thermal capacity.

The actual (dynamic) rating of the MSH-LYC line during the period 7/17/2005 to 8/17/2005 is shown in Figure 2. It can be seen that the actual rating exceeded the static rating over 96% of the time.

There are a number of methods to increase the capacity of line, such as raising structures, reconductoring, or retensioning. An alternative to these more costly approaches to measure and monitor the true rating of the line during all system conditions. Dynamic rating is an approach which harnesses unused capacity by monitoring the status of the line and/or weather conditions and calculating the actual rating in real-time. By using actual, rather than assumed, weather conditions, dynamic rating can simultaneously increase both capacity and reliability.

V. THE THERMALRATE SYSTEM

The ThermalRate System is a dynamic line rating approach that uses the patented ThermalRate Monitor TRM) to determine a line's rating by measuring how actual weather conditions heat and cool a conductor. The TRM includes two conductor replica sections which are similar to the actual conductor in material, size, and surface (see Figure 3). Each of the replica sections includes an embedded temperature sensor, and one of the replica sections contains an electric heater.

Figure 3 – TRM Conductor Replica Section

The TRM's internal microprocessor measures the two replica temperatures to determine the effective wind speed and solar effects (direct and indirect) seen by the TRM. The heater power is constant, so increased effective wind causes the heated replica's temperature to fall nearer to the unheated replica's temperature. The relationship between conductor temperature and wind is identified by IEEE-738, "IEEE Standard for Calculating the Current-Temperature Relationship of Bare Overhead Conductors." The effective wind speed also takes into account the various forms of precipitation. The TRM then calculates the actual rating of the line by again using IEEE-738 with the effective wind speed and the parameters of the line conductor.

A ThermalRate System consists of one or more ThermalRate Monitors (TRMs). Each TRM includes a sensor mounted at approximate line height, a controller mounted somewhere below the sensor, an antenna for radio communication, and an optional solar power supply for installations where AC power is not available. TRMs are installed at critical locations along the line, and the lowest TRM rating is used as the rating of the line. The system components are shown in Figure 4.

The TRM Controller includes a microprocessor which controls the measurements, stores information about the actual conductor, calculates the line rating, and supports DNP3 communications so the line ratings can be easily reported to SCADA.

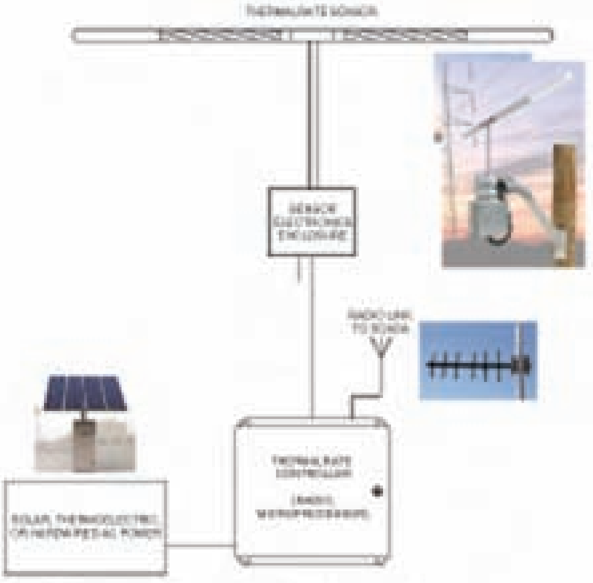

Figure 4 – ThermalRate Monitor Components

VI. SYSTEM INSTALLATION

The MSH-LYC line is a 4.1-mile long, 115 kV line between Marshall and Lyon County substations located east of Marshall, Minnesota. The land in this area is flat, with fields, few trees, and frequent wind. The line consists of Penguin T2 397.5 kcmil conductor with the exception of the slack span at Marshall, which uses Hawk 477 ACSR. The line runs East-West, except for the Marshall slack span and a single span near LYC, which run North-South. A diagram of the line is shown in Figure 5.

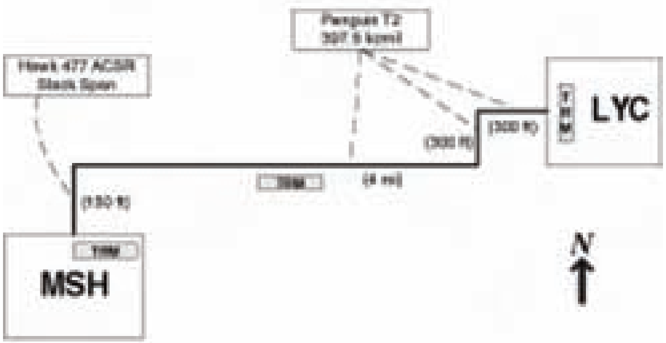

Figure 5 – Line Configuration and TRM Locations

Personnel from Marshall Municipal Utilities, Xcel Energy, and EDS selected TRM locations based on line orientation, ease of installation, and availability of AC power. Three TRM locations were selected along the MSH-LYC line, one at Marshall Substation (MSH), one at Lyon County Substation LYC), and one at the approximate line midpoint (MMT).

The TRMs at the substations are powered by DC station power, while the midpoint TRM is solar powered.

Each TRM (Sensor and Controller) is installed on a wood distribution pole set for this purpose. The TRM Controllers are installed near ground level for easy access as shown in Figure

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Figure 6 – TRM Controller at Lyon County Substation (LYC)

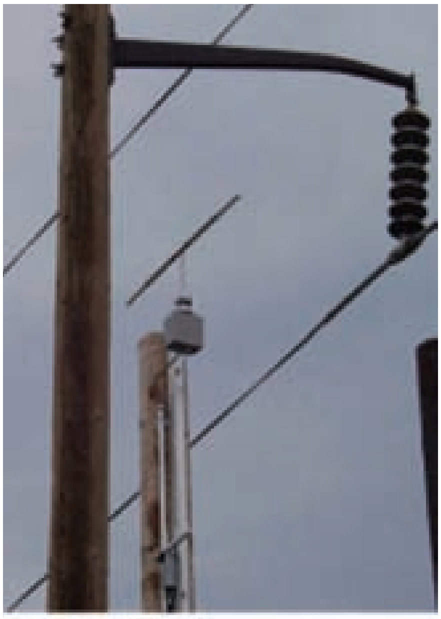

Figure 7 – TRM Sensor at Midpoint (MMT)

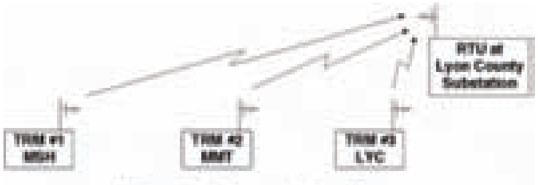

Figure 8 – Communications Diagram

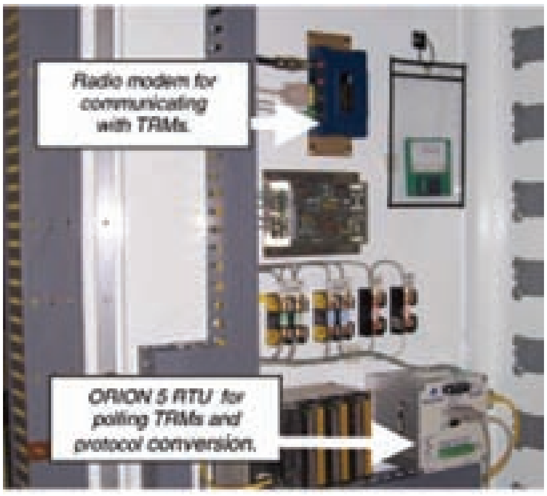

Figure 9 – RTU at Lyon County Substation

6. The TRM Sensors are installed at a height of 30', so that they experience the same wind conditions as the line itself. The 30' elevation was chosen because it is the average height of the lowest conductor under maximum sag conditions. An installed TRM Sensor is shown in Figure 7.

The TRM Sensors are oriented in the same direction as the line being monitored. The TRMs at MSH and MMT are East-West to monitor the main length of the line. The LYC sensor is North-South to monitor the single span at LYC sub. The span of Hawk ACSR at Marshall Substation has a higher rating than the North-South span at LYC and does not need to be monitored.

Each ThermalRate Controller includes a spread-spectrum radio modem for communicating the rating information to SCADA. The communication scheme is shown in Figure 8.

Each TRM responds directly to DNP3 protocol SCADA requests from an RTU at Lyon County Substation. The primary RTU at LYC supported only Modbus protocols, so an inexpensive NovaTech Orion 5 RTU was provided to convert DNP3 protocol information to Modbus. The RTU includes communication failure detection logic as well as logic to report the lowest of the three TRM readings. Figure 9 shows the communications equipment installed in an existing cabinet at Lyon County Substation.

VII. OPERATIONS

The ThermalRate System communicates the LYC-MSH normal and emergency ratings to Xcel Energy's SCADA system. Xcel Energy Control Room Operators monitor steady state and post-contingent loading on LYC-MSH and compare the results with the normal and emergency dynamic rating provided by the ThermalRate System. Exceeding either of the dynamic ratings would require curtailment of wind generation on Buffalo Ridge.

VIII. RESULTS AND CONCLUSIONS

The ThermalRate System was installed beginning in May of 2005, was commissioned in June, and has been in service since that time. The actual ratings measured by the ThermalRate System are generally much higher than the static rating, as can be seen in Figure 10. This is primarily due to the actual wind speed, which is typically stronger than the assumed 2 ft/s wind. The rating spikes are likely due to precipitation.

Figure 11 shows the ratings and the LYC-MSH loading over a two-day period around July 20, 2005. While there appears to be a large margin between the

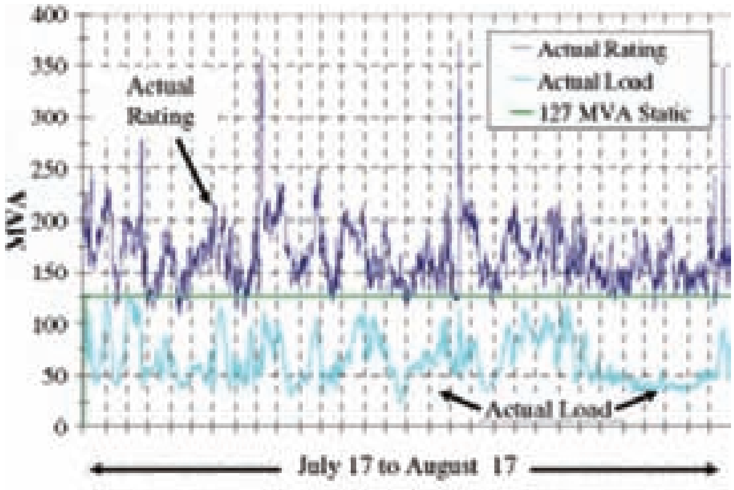

Figure 10 – Ratings for 1 month period

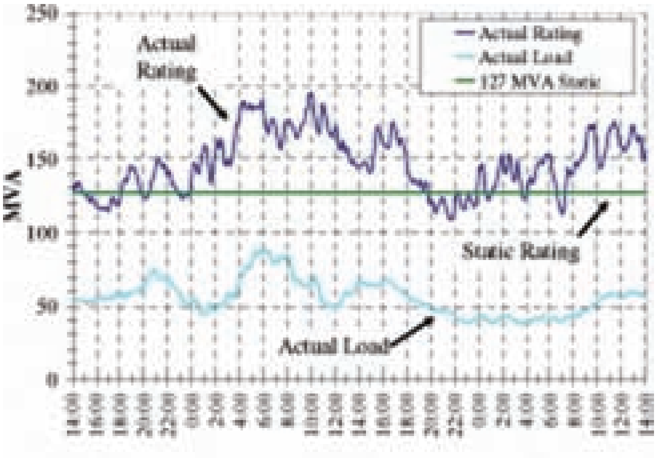

Figure 11 – Ratings for 2 day period

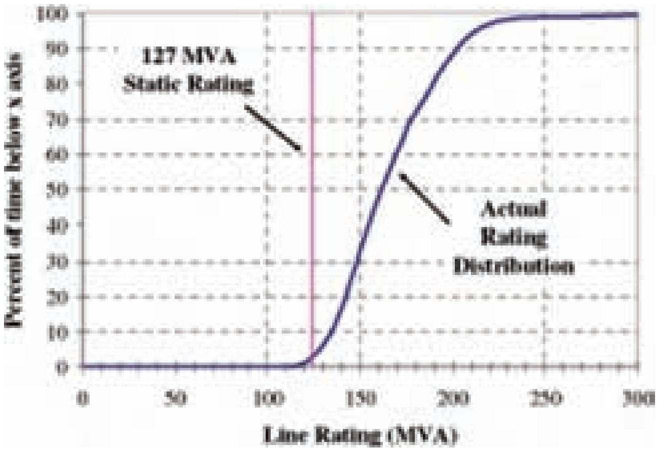

Figure 12 –Cumulative Line Rating, July 17 – August 17

actual load and the static rating, the line is constrained due to post-contingency loading. In other words, while the actual load on the line is shown in the figure, the more pertinent value is the post-contingent load, i.e. the load that would appear on the line if there were a loss of another line in the system. Post-contingent load is continuously calculated and displayed in the Xcel Energy Control Room. Post-contingent load is not recorded so it cannot be included in the figure, but at no time during this period did the actual load exceed the post-contingent load.

Figure 11 also shows short durations where the dynamic rating was less than the static rating due to very low wind speed. This figure illustrates how dynamic rating is particularly effective in wind generation applications – at times when wind generation is high due to strong winds, those same winds are typically providing line cooling and increased rating. Conversely, the periods of low rating occurred when wind generation was low, so full line capacity was not required.

Figure 12 provides a cumulative distribution of line rating.

Notice how the actual line rating is above the static 127 MVA static rating 96% of the time.

Figures 10-12 illustrate how the ThermalRate System allowed Xcel Energy and Marshall Municipal Utilities to increase the LYC-MSH line rating and recognize previously unused capacity. The recognition of this capacity has allowed higher steady state and post-contingent flows and eliminated the need to curtail Buffalo Ridge wind generation.

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