THE THERMALRATE SYSTEM: A SOLUTION FOR THERMAL UPRATING OF OVERHEAD TRANSMISSION LINES

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Introduction

Implementation of real-time thermal rating is an attractive solution for increasing overhead line power transfer capability. Real-time rating can increase transfer capability with lower cost and shorter lead-time than alternative methods which require physical modifications to the line. A real-time rating system can reduce congestion costs and avoid unnecessary load shedding during contingencies.

The ThermalRate System is a new system from Shaw PTI which harnesses existing line capacity by continuously monitoring and determining the actual line rating. The ThermalRate System offers many advantages over competing technologies, including outage-free installation and superior accuracy over all load and weather conditions.

Overhead Line Thermal Rating Fundamentals

The thermal rating of an overhead line is the maximum current that the line can transfer without overheating. The thermal rating is a function of the weather conditions seen along the line, including wind speed, wind direction, air temperature, and sun. Other secondary influences (which are not considered in IEEE 738) can also affect the rating. These include the various forms of precipitation, turbulent air flow, and indirect solar radiation.

Figure 1 shows that over time a line has a distribution of ratings. This figure shows a full year of actual rating data. Low ratings correspond to times of low wind speed, full sun and/or high ambient temperature. High ratings correspond to times of high wind speed crosswise to the conductor, low ambient temperature, no sun and/or precipitation.

The thermal rating of most lines is limited by the conductor sag. As electrical current increases through an overhead conductor, the conductor temperature increases and therefore the conductor sags. Each line has a minimum clearance to ground, which must never be violated for safety reasons. The thermal rating is the maximum current, which results in the conductor just sagging down to the minimum clearance. Any additional current would result in too much sag and a subsequent safety problem. Most utilities have adopted a semi-worst-case weather approach to establish the line’s “static rating”. Common weather assumptions are simultaneous conditions of 40 C (104 F) air temperature, full sun, and 2 ft/s (1.4 mph) wind speed crosswise to the conductor. The static rating for the line shown in Figure 1 is only 920 amps. In reality, though, the actual line rating rarely falls to the static rating. Therefore, using the static rating approach can waste a significant portion of the line’s transfer capacity.
Monitoring approaches try to harness this wasted capacity by permitting safe operations above the static rating of the line. The data can be used for either off-line rating analysis or in a real-time mode. In the off-line mode, the data can be used to perform a better evaluation of the static rating. Seasonal or time-of-day ratings can be created. Off-line analysis can also be used to determine how much can be gained by real-time operation. In the real-time mode, the ratings are reported to the operator in real-time. They can be posted on the existing SCADA display.

**General Thermal Rating Calculation Method**

An equation to calculate conductor rating is developed by first recognizing that the total input heat (per unit length) to a conductor must equal the total output heat in the steady state. The conductor is heated by ohmic losses \((I^2R)\) and solar input, and it is cooled by convection and radiation. Equation (1) and Figure 2 show this main “heat balance” equation:

\[
Q_{solar} + I^2R = Q_{convection} + Q_{radiation}
\]  

(1)

where:

- \(Q_{solar}\) Heat input due to solar radiation, W/ft.
- \(I^2R\) Heat input due to line current
  (\(R\) is a function of conductor temperature), W/ft.
- \(Q_{convection}\) Heat output due to convection (a function of wind, air temp, conductor temp), W/ft.
- \(Q_{radiation}\) Heat output due to radiation (a function of air temp and conductor temp), W/ft.

Now, the equation can be reworked to solve for current as a function of the weather conditions. The \(Q_{convection}\), \(Q_{radiation}\), \(Q_{solar}\), and \(R\) terms are all functions of weather conditions and of conductor temperature. If the
weather conditions are measured and the conductor temperature is set to the maximum allowable conductor temperature, the calculated current is the rating current as shown in Equation (2).

\[ I_{\text{rating}} = \sqrt{\frac{Q_{\text{convection}} + Q_{\text{radiation}} - Q_{\text{solar}}}{R}} \]  

\[ (2) \]

The ThermalRate System

There are five main commercially available methods for performing transmission line thermal rating monitoring: weather monitoring, tension monitoring, sag monitoring, line temperature monitoring, and the ThermalRate System. The ThermalRate System is a complete dynamic rating system which utilizes ThermalRate Monitors placed at a number of locations along the transmission corridor. Each ThermalRate Monitor uses a ThermalRate Sensor, a patented device based on a conductor replica approach. The ThermalRate System overcomes several shortcomings of other monitoring systems.

Some of the advantages of the ThermalRate System are listed below:

A. Accuracy at Normal Electrical Loading

Tension, sag, and line temperature monitoring have a common disadvantage in that they cannot determine ratings during times of low electrical load. For example, if a tension monitor is placed on a line with normally low load (less than about 1 amp/mm² or 35% of the line’s static rating), it becomes physically impossible to determine the rating, since the conductor temperature rise above air temperature is very small. The ThermalRate System described in this paper uses a different approach, which allows line rating determination without dependence on the actual line load. With this approach, the rating can be provided to the system operator before as well as during the contingency. At present, most lines have fairly low load during normal system operating conditions. The possibility of high line load occurs during contingency loading scenarios. For example, it may be determined that if a certain backbone 345 kV line is lost in a contingency, the surrounding lower voltage lines (115 or 69 kV) may become overloaded. Therefore, the load on the 345 kV line is limited to avoid this. Under normal conditions, the static rating of the 69 kV lines limits the total power transfer capability even though they may have minimal load.

B. Accurate Measurement of Weather Conditions

Weather monitoring can be used to effectively determine overhead line ratings. However, at low wind speeds, when knowing the rating is most important, common rotating wind speed sensors stall. This will worsen over time due to bearing wear. Also at low wind speeds, the wind direction can become variable (turbulent) in speed and direction and therefore its effect on conductor rating becomes hard to determine. The ThermalRate Sensor has no stall speed and in fact becomes more accurate at low wind speeds. Additionally, the sensor considers the influence of all weather conditions, including precipitation, and direct and indirect solar.

C. Effort and Cost of Installation

Monitor installation can be very expensive if it requires physical modifications of the line. In addition, if the installation requires a line outage, this outage might be very slow or impossible to obtain. Sag monitors and line temperature monitors can often (but not always) be installed live by a line crew. Although a tension monitor can theoretically be installed live, many utilities have rules preventing such work. Installation of a tension monitor involves selecting a favorable dead-end structure and disconnecting one of the insulator strings in order to insert a strain gauge. The ThermalRate Monitor has low installation cost since it does not require an outage to install, does not need to make contact with the actual conductor, and is flexible as to where it can be located.
D. Maintenance

The ThermalRate Monitor has a very simple design with no moving parts. As a result, it is much more rugged and reliable than conventional monitors.

Description of the ThermalRate Sensor

The ThermalRate Sensor is based on a conductor replica and determines the line capacity by measuring how the weather conditions heat and cool the conductor. The sensor consists of two aluminum rods which function as simple conductor replicas. The replicas are chosen to be the same material and diameter as the line conductor (Figure 3).

![Aluminum conductor replica](image)

The heated and unheated replicas are relatively long in order to minimize the affect of thermal boundary losses. An internal thermocouple near the longitudinal center measures the temperature of each replica. The ThermalRate Sensor is located near the line and pointed in the same direction as the line conductors (Figure 4) in order to experience the same weather conditions as the line itself.

![ThermalRate Sensor](image)

One of the replicas incorporates an internal resistive heater (running at a nearly constant wattage) to increase the replica temperature above that of the other replica. The weather conditions influence the temperatures of the two conductor replicas. By comparing the temperatures of the two replicas, the line capacity can be calculated and supplied to the power system operator.

References