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How Hot Is It?

A Survey of Temperatures Inside Medium-Voltage Electrical Enclosure across North America

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***Abstract*— While circuit owners often monitor cable and transformer temperatures on their critical circuits, the temperatures that exist inside distribution-voltage electrical enclosures have not been well documented. This paper studies the temperatures recorded inside electrical enclosures throughout North America. The results were collected over the course of a year at four geographically different locations in cryic, mesic, thermic and hyperthermic soils and from systems operating with phase to phase voltages of 15 through 35kV. This paper illustrates the effects that the ambient conditions, seasonal load fluctuation and installation factors have on the temperatures measured inside enclosures. The internal temperatures impact the safety and long-term durability of the ancillary equipment often contained within distribution-class electrical enclosures such as cable rejuvenation equipment, rejuvenation fluid, smart sensors, partial-discharges sensors, fault indicators, etc. and this data should be given consideration in the standards and installation guidelines for those devices.**

***Keywords*— temperature; data logging; monitoring; electrical enclosure; pad-mount transformers; cable accessories; cable testing; cable rejuvenation.**

I. INTRODUCTION

This paper presents the results of a temperature survey conducted over a twelve-month period inside pad-mount transformers at four geographically different environments across North America.

Over the past half century, more than 600,000 kilometers (379,000 miles) of solid-dielectric medium-voltage cable has been installed underground [1]. Of these cables, the majority being installed in underground residential distribution (URD) circuits and terminated in above ground electrical enclosures such as switchgear and pad-mount transformers.

As more and more distribution networks are placed underground, the emphasis on maintaining reliability and extending the service life of those underground systems increases. This trend leads to the increased popularity of cable injection [2], real-time system monitoring and diagnostic testing [3] that require equipment to be placed in electrical enclosures.

For underground systems, the industry provides design standards and installation guides for key component such as pad-mount transformers [4], concentric-neutral cable [5], dead-front cable terminations [6], etc. While these documents include the normal environmental temperature ranges for each device during operation, there has been little published data to fully describe the temperatures that exist inside electrical enclosures. Such data would be beneficial in developing similar installation guides and design standards for the cable system accessories that reside in the enclosures such as the lubricants and greases used during craftwork, permanently-installed test equipment, fault indicators, cable-injection equipment, etc.

II. EXPERIMENT

Four geographic locations were selected across North America to study based on the diversity of their electrical distribution voltages and their environmental conditions (Table 1). The environment for direct burried cable systems can be categorized by the mean average soil temperatures used in labeling regions as cryic, mesic, thermic and hyperthermic. Such measurements are taken at a depth of 0.5 meters.

TABLE I. DESCRIPTION OF THE FOUR TEST REGIONS BY ENCLOSURE TYPE, VOLTAGE CLASS, SERVICE TYPE AND SOIL TYPE

Region	*Canadian Plains*	*Rocky Mountains*	*Gulf Coast*	*Desert Southwest*
Enclosure Type	Pad-mount Transformer	Pad-mount Transformer	Pad-mount Transformer	Pad-mount Transformer
Voltage Class	28kV	15kV	35kV	15kV
Service Type	Residential Distribution	Residential Distribution	Residential Distribution	Residential Distribution
Soil Type (mean annual temperature range)	Cryic[a] (0-10C)	Mesic[a] (8-15C)	Thermic[a] (12-22C)	Hyper-thermic[a] (22-28C)

[a] Determined by method outlined by Bertini & Vincent in [7].

It was desired to monitor temperature changes inside an electrical enclosure over a twelve-month period. When selecting the data logger, consideration was given to the real-world battery life, operating temperature range, memory size, physical dimensions, waterproof design and its ability to function in areas with high magnetic fields. The data logger selected was self-contained and housed in a waterproof aluminum canister measuring approximately 2.8cm (1.10in.) in diameter by 12.0cm (4.71”) in length. The data loggers were programed to record one temperature reading each hour.

For each geographic location, two transformers were selected based on their exposure to full-sun and full shade. Inside each enclosure, a single data logger was installed near the ceiling of the enclosure. Following installation, a technician was scheduled to return to each transformer after approximately six months to change the battery, download a partial set of data and to verify proper operation.

III. DATA

Following the conclusion of the survey, the data was compiled and checked for normality using a generalized linear regression model (Figure 1). The model confirms good normality of the data.

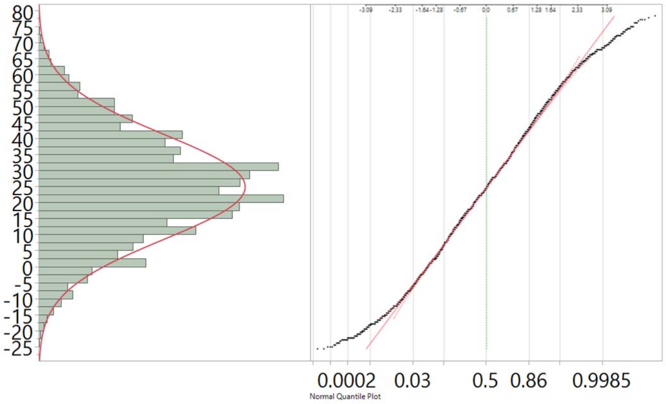

Fig. 1. Check for normality of cumulative dataset from all regions using a generalized linear regression method.

A. *Effect of Geographic Region*

Using the boxplots shown in Figure 2, the data was organized by geographic region to chart the temperature distribution. The regional effect appears significant, with each region having a unique mean, interquartile range and skew distribution. The strong effect that geographic region has on temperature is further demonstrated by its leverage plot (Figure 3).

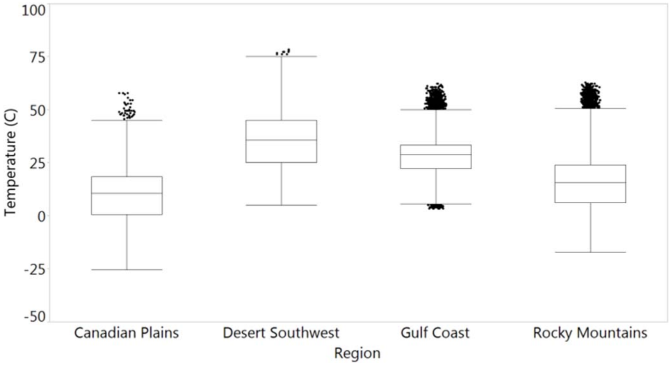

Fig. 2. Distribution of temperature by geographic region.

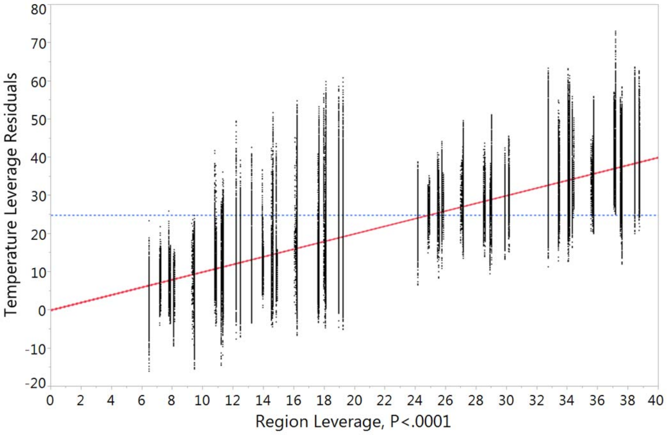

Fig. 3. Leverage plot for the effect of geographic region on enclosure temperatures.

The distribution of the change in enclosure temperature over the course of one hour was plotted by region (Figure 4). All regions displayed a fairly tight distribution with the widest range occurring in the Rocky Mountain dataset. Outliers that fell outside 1.5 times the interquartile range (IQR) were observed in all four regional datasets, with the most significant occurring in the Rocky Mountains data (+/-30^{0}C/hour). Each of the outliers were examined and confirmed to be real, with the steep change following a smooth curve that crests over the following several hours. Upon closer examination of the data, it is believed that these large changes occur due to load requirements while smaller differences were due to weather.

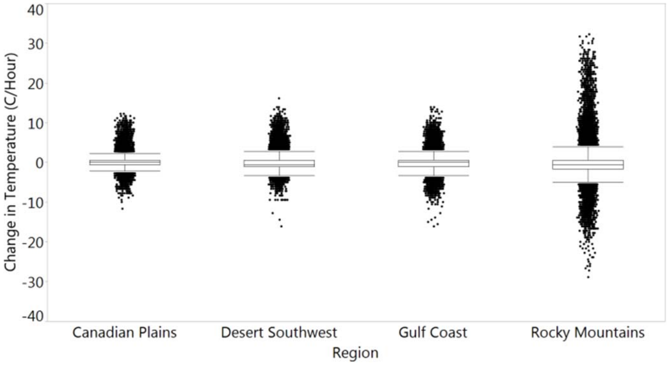

Fig. 4. Distribution of change in temperature over the course of one hour by geographic region.

B. *Effect of Time of Year*

Seasonal effects were examined by plotting the distribution of temperature data recorded over the course of each month in the box plots shown in Figure 5. For each month, the subsets of data recorded in full sun (red) and in full shade (blue) were plotted separately. As expected, the effect of monthly variation is strongly significant in both datasets, with a steady increase in the temperature occurring throughout the spring and reaching plateau in June that is maintained through August. A steady decrease in temperature distribution occurs in fall and is continued through the winter. The leverage plot shown in Figure 6 confirms that month has a medium effect on enclosure temperature.

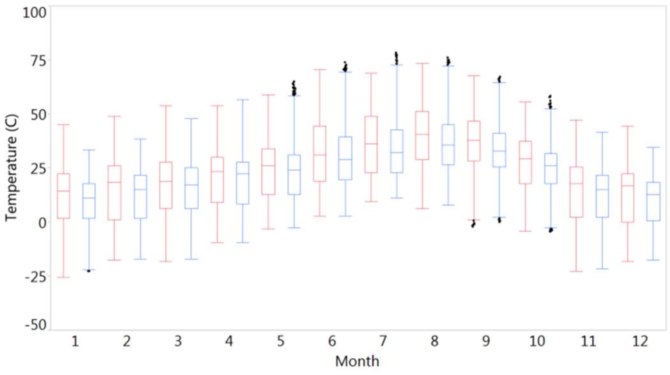

Fig. 5. Distribution of enclosure temperature by month for sun (red) and shade (blue).

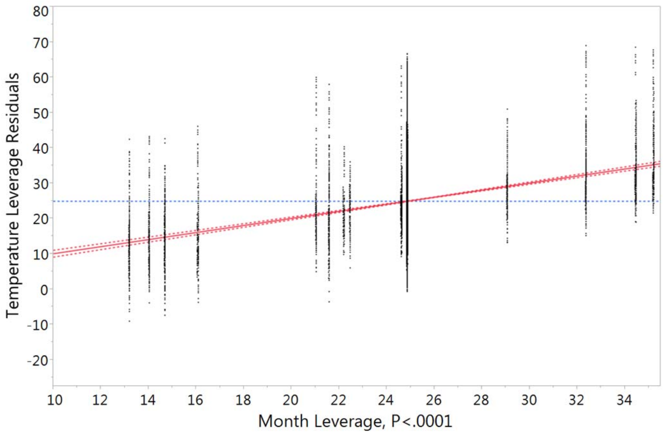

Fig. 6. Leverage plot for the effect of month on enclosure temperature.

C. *Time of Day Effect*

The time of day effect was examined for its influence by plotting the cumulative data distribution recorded in all enclosures over the course of each hour of a day (Figure 7). The effect is slight but noticeable as temperature distributions rise during the daytime hours and fall during the night. Due to the confounding issue of random load changes time of day was found to be much less significant than expected. The leverage plot (Figure 8) further confirms a low effect between time of day and enclosure temperature.

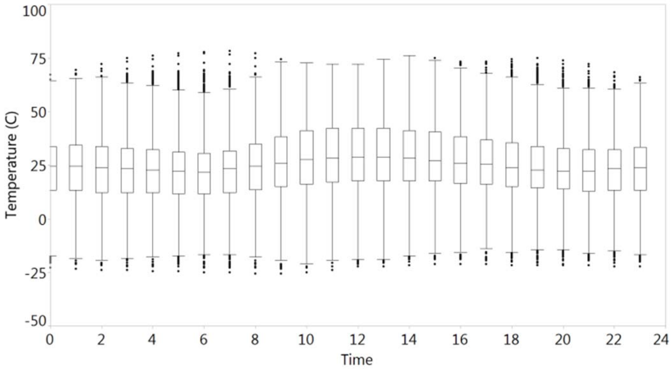

Fig. 7. Distribution of enclosure temperature data by time of day.

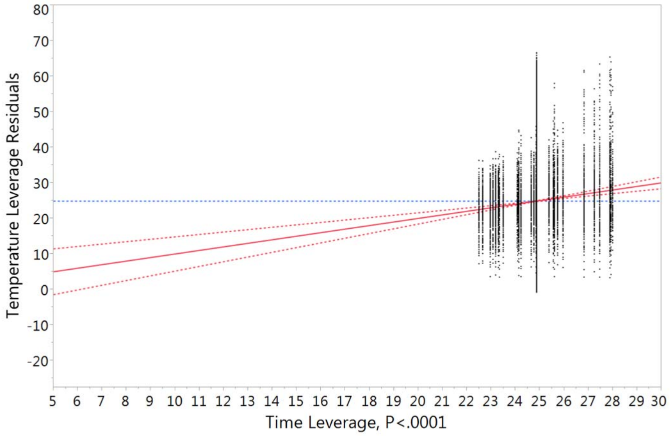

Fig. 8. Leverage plot for the effect of time of day on enclosure temperature.

D. *Effect of Sunlight & Shade*

Regional data was separated to investigate the effects that direct sunlight and full shade have on enclosure temperatures (Figure 9). The general effect was found to be insignificant as the distributions for sun (red) and shade (blue) in each region closely mirror each other in mean, distribution, and skewness.

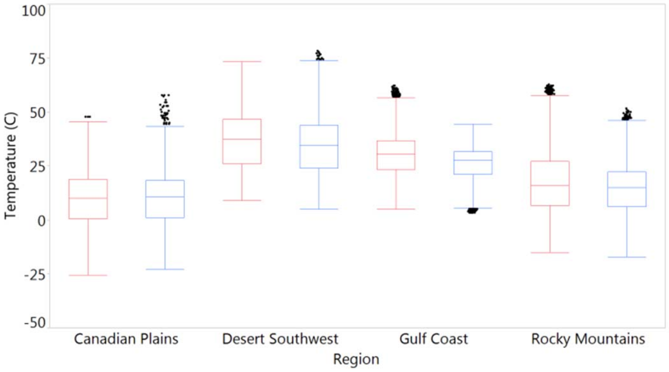

Fig. 9. Distribution of enclosure temperature in direct sunlight (red) and full shade (blue) separated by geographic region.

IV. DISCUSSION

A. *Linear Regression Model*

While not ideal, a generalized linear regression model can be used to compare compounding effects and easily explain interactions. The results of the generalized linear regression model for the temperature data presented in this paper are summarized in Tables 2 and 3. Considering the factors of region, month, time and sun along with their interactions, the generalized model accounts for over 77% of the overall temperature variation and therefore provides an acceptable predictor for determining enclosure temperature.

The independent effects of the four variables and their interactions were ranked according to their Logworth value in Table 3. From the table, region clearly demonstrates the strongest effect. The interaction of month crossed with time demonstrates a stronger effect than the independent effects of month or time.

TABLE II. SUMMARY OF FIT FOR GENERALIZED LINEAR REGRESSION MODEL OF DATA

Property	***Value***
RSquare	0.772527
Rquare Adj	0.771415
RMS Error	7.841964
Mean Response	24.8749
Observations	118835

TABLE III. EFFECT SUMMARY OF REGION, MONTH, TIME, SUN AND THEIR INTERACTIONS

Effect	***LogWorth***	***PValue***
Region	25845.88	0.00000
Month*Time	1033.487	0.00000
Month	986.707	0.00000^
Time	56.366	0.00000^
Month*Time*Sun	35.094	0.00000
Sun	5.773	0.00000^

Removing the effects of sun and its interactions from the model yields a 76% coefficient of determination that confirms the minimal effect noted in the boxplots discussed in Section D of the previous section.

A more sophisticated and appropriate Bootstrap Forrest mixed model was performed and found to account for over 85% of all temperature variation. However, this type of model requires advanced statistics beyond the scope of this paper and so was not discussed here.

B. *Future Work*

Following this study, the authors would like to see additional work performed that expands the published and peer-reviewed body of knowledge relating temperatures found in medium-voltage electrical enclosures. It is suggested that future surveys include more geographic regions and minimally include data on the time of year and time of day. As these three variables and their interactions account for only 76% of the temperature found according to the model, it is suggested that other variables be explored such as cable loading, ambient temperature, humidity and wind.

C. *Normal Operating Temperature Range*

While additional work is suggested to refine our understanding, the data can begin to define the normal operating temperature range inside electrical enclosures across North America. Referring to the boxplots in Figures 2, the normal range can be determined by the observed high and low temperatures. The Canadian Plains dataset reveals that on the coldest part of the coldest day, the lower bound of the 95 percent IQR is -25 degrees Celsius. Similarly, the Desert Southwest dataset reveals that on the hottest part of the hottest day, the upper bound of the 95 percent IQR is 75 degrees Celsius.

V. CONCLUSION

This paper presents the results of a temperature survey conducted over a twelve month period inside electrical enclosures at four geographically different environments across North America. The data establishes a basic understanding of normal temperatures inside enclosures defined by the range of -25 and 75 degrees Celsius. A generalized linear regression model of the data predicts enclosure temperature to within 76% accuracy using the effects of region, month, time and their interactions. Further research is suggested to build on the work presented in this paper to further refine the understanding of the normal temperature range for enclosures used by the design guides and industry standards for medium-voltage underground distribution systems.

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