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Guide
for
EVALUATING the EFFECT of SOLAR RADIATION
on OUTDOOR METAL-CLAD SWITCHGEAR

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FOREWORD

The original Guide for Evaluating the Effect of Solar Radiation on Outdoor Metal-Clad Switchgear was prepared as a Committee Report by the Switchgear Assemblies Subcommittee of the Switchgear Committee. This Report was presented as a Technical Paper at the AIEE Winter General Meeting in New York, New York, January 18-22, 1954. In October 1955, it was issued by the AIEE Standards Committee as Publication 955.

The current revision is primarily a clarification of the original Guide and an extension of the application curves to cover the 3000-ampere rating of metal-clad equipment. Also, the original Guide referred to U. S. Weather Bureau Technical Paper No. 9, dated December 1948, and the reference temperatures used in the Guide were based on the "average daily highest temperature" for various localities as published in this paper.

The Weather Bureau has advised the Subcommittee that Technical Paper No. 9 has been superseded by Technical Paper No. 31, dated November 1956. The latter paper lists the "monthly normal maximum temperature" which is equivalent to the "average daily highest temperature" in Technical Paper No. 9 except for minor variations which are due to differences in the period of time covered by the data. Values in Technical Paper No. 31 either cover or are adjusted to a standard time period of 30 years (1921-1950 inclusive) and the U. S. Weather Bureau recommends that these values be used rather than the ones previously given in Technical Paper No. 9.

An additional feature of this edition is the addition of monthly normal maximum temperatures for 33 Canadian locations—extracted from Bulletin CDS 7-59 of the Meteorological Branch of the Department of Transport, Canada, for the 30 year period from 1921 through 1950 inclusive.

ACKNOWLEDGMENT

The Institute wishes to acknowledge its indebtedness to those who have so freely given of their time and knowledge and have conducted the theoretical and experimental work on which this publication is based. This publication was prepared by the following members of the Switchgear Assemblies Subcommittee of the Switchgear Committee.

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INTRODUCTION

Over the past several years, outdoor metal-clad switchgear has reached a position of widespread application comparable to that of indoor gear. Its satisfactory record for many years in cold, temperate, and hot climates has contributed to this increased usage. However, there are conditions affecting its application which are different from those for indoor gear and warrant special consideration.

This was realized and a study of the situation was undertaken by the AIEE Switchgear Assemblies Subcommittee. It was first determined that temperature data were not available on fully loaded units in the field. Outdoor laboratory and field testing was then tried, and it became evident, due to uncontrollable conditions, that accurate and complete data suitable for establishing the current-carrying capability of outdoor metal-clad switchgear could not be obtained. Next, indoor testing simulating outdoor conditions was resorted to. Further valuable data were accumulated, but there is still no absolute relationship between results obtained indoors and conditions existing outdoors. However, based on these investigations, sufficient data are now available for the preparation of a Guide for using outdoor metal-clad switchgear in various climates.

SCOPE

The general information in this Guide is applicable to all forms of outdoor metal-enclosed switchgear. Specific data are given in Figure 2 for outdoor metal-clad switchgear.* The many combinations of sizes and ratings in similar housings make it impractical to provide equivalent information for outdoor low-voltage metal-enclosed air circuit breaker switchgear. Data are not yet available for specific recommendations on outdoor cubicle-type switchgear, isolated phase bus, outdoor power circuit breakers and other switchgear equipment or components.

PURPOSE OF GUIDE

Switchgear will perform satisfactorily and have a reasonable life when operated within the temperature limits established in American Standard C37.20-1955. In outdoor applications, the limiting temperatures result from the net effect of internal losses and external influences, principally the sun, wind, and local ambient temperatures. All of these must be considered in determining the current-carrying capability of outdoor metal-clad switchgear.

American Standard C37.20-1955 specifies the temperature rise above a standard ambient temperature of 40C. This is satisfactory for indoor applications where the temperature rise is due entirely to heat release. However,

when the gear is located outdoors, several additional factors require consideration. The effect of sun, wind, ventilation, ambient temperature, etc. on internal temperatures will be considered in this Guide.

The magnitude of these factors will vary geographically and from season to season. The time relationship of maximum breaker loads with respect to maximum ambient temperature is important. IT IS NOT PRACTICAL TO DESIGN SWITCHGEAR ON THE BASIS THAT ALL ADVERSE FACTORS REACH THEIR MAXIMA COINCIDENT WITH MAXIMUM LOADS. IF THIS DOES NOT OCCUR, FULL CURRENT RATINGS MAY BE REALIZED. Recommendations will be made to point out the cumulative effect of these various influences.

OPERATING LIMITATIONS

Temperature limitations for metal-enclosed switchgear are established at a value which will insure satisfactory life of the insulation. Operation at higher temperatures than permitted by the Standard will result in shortened life, but if the temperature of the insulation goes above normal for a few hours during a few days of the year, the effect on total life is hardly measurable. This is very different from the establishment of higher short-time ratings which might be repetitive on a continuous day-to-day basis. The hazard of immediate breakdown is not increased unless extreme temperatures are reached.

Outdoor metal-enclosed switchgear is usually designed with more restricted ventilation than indoor gear with the object of excluding wind-blown dust and dirt. The effect of this is a tendency toward somewhat increased internal temperatures of outdoor switchgear compared to indoor installations with equivalent circuit breakers and buses. These conditions have been recognized in designs. With this restricted ventilation, the effect of solar radiation on an enclosure will cause the air immediately under the roof to be relatively warm. Electric parts, therefore, located near the roof will be operated in air considerably warmer than that surrounding equipment in the center or lower part of the switchgear units. Cable insulation of certain types cannot be operated in as high air temperatures as others. If cables are located in the upper part of housings, insulation with the best thermal characteristics should be selected. American Standard C37.20-1955 states in effect that the average temperature of the air surrounding outgoing insulated cables in any compartment shall not exceed 55C with a maximum average ambient temperature of 40C outside the structure. In many cases the effect of solar radiation alone will raise the inside temperature above that permitted by the Standard. The insulation and size of conductors in this location should be carefully con-

* As defined in American Standard C37.20-1955 for Switchgear Assemblies and Metal-Enclosed Bus, Definition 27-102.

sidered by both manufacturers and users.

End units, particularly those exposed to the sun during periods of heavy load, should be considered on a different basis from the others in determining loading, conductor sizes, and cable insulation.

In addition to the effect on insulation, high internal air temperatures will increase the temperature rise of the conducting parts. If circuit breakers are properly maintained, no adverse effects will result if their temperatures exceed allowable limits by a few degrees for short intervals during a few days of the year. All primary connections in metal-clad switchgear are silver surfaced or the equivalent, and no trouble should be experienced with them if rated temperatures are exceeded under similar conditions. Here again it is important to realize the difference between increased temperatures, due to outside influences which occur infrequently, as compared to higher short-time ratings which might be repetitive on a continuous daily basis.

EXTERNAL INFLUENCES ON INTERNAL OPERATING TEMPERATURES:

A. Ambient Temperatures

The ambient temperature surrounding switchgear is the base to which the temperature rise of insulation and electric parts is added. At rated current, the conducting parts have an established temperature rise above the outside air. If the temperature of this air is lower, the temperature of the electric parts will be correspondingly reduced. In all test work, measurements are made with the ambient temperatures determined by the methods established in American Standard C37.20-1955, and the thermal performance of the equipment is based on the temperature rise above these ambient temperatures. Outdoor ambient temperatures vary widely in most localities over a 24-hour period and provide a varying influence on the internal temperatures of switchgear. Under the more stable conditions affecting indoor applications it is possible to establish a reasonably accurate relationship between ambient temperatures and the temperature rise of electric equipment. However, with the changing conditions which exist outdoors, it was found that it was impossible to get test data sufficiently accurate and consistent for use in establishing the current-carrying capability of switchgear. The establishment of ambient temperatures over a considerable period of time, as would be necessary to fix a value to be used for determining the loading of switchgear, is a rather lengthy procedure. Readings of ambient temperature should be taken in standard U. S. Weather Bureau enclosures. The construction of these can be obtained from any U. S. Weather Bureau Station. The house for the thermometer should be located in a position which will have air of about the same temperature as that around the switchgear. In outdoor locations there is no significant variation with respect to the top, middle, or bottom of the structure. However, the thermometer should not be affected by heat reflection from the ground.

The U. S. Weather Bureau in Technical Paper No. 31 (Nov. 1956 and future revisions thereof) titled "Monthly Normal Temperatures, Precipitation and Degree Days",

covers data taken or adjusted to a standard time period of 30 years from 1921 to 1950 inclusive. These data were obtained from Weather Bureau Stations in the United States, Hawaii, Alaska, the West Indies and Pacific Islands and are believed to be the best information available for determining reference temperatures for the purpose of this Guide. The monthly normal maximum temperatures in Technical Paper No. 31, (reproduced in this Guide) are given for each month of the year. The monthly normal maximum temperature for the month of July, for example, is computed by adding the maximum temperature for each day in July in a particular year and dividing the sum by the number of days. This provides the monthly normal maximum temperature for July of that year. The yearly temperatures for that month are averaged to provide the figure shown in the tabulation. It is recognized that an average obtained in this way may be lower than an average based on some particular shorter period of time.

The absolute maximum temperature for a particular month (available in other U. S. Weather Bureau records) is the maximum temperature that has ever been reached in a particular locality. Ordinarily such extremes of temperature would occur for only a few hours on one day over a period of several years. It does not seem feasible to design and apply switchgear on this basis, and therefore the monthly normal maximum temperatures are recommended for determining the continuous current-carrying capacity of outdoor metal-clad switchgear in the locality where it is to be installed and operated. An examination of this tabulation will show that in the hot months of the year the 40C (104F) standard ambient temperature was exceeded only in Arizona and Nevada. In most localities the monthly normal maximum temperature is considerably below 40C (104F) leaving a margin which should help to offset some of the adverse factors caused by higher temperature and provide longer than normal insulation life.

There are many Weather Bureau Stations where long-time records of the monthly normal maximum temperatures are available in addition to those listed in Technical Paper No. 31. Where such additional local Weather Bureau data can be obtained, a check should be made to be sure that the temperature data used for determining current-carrying capacity are representative of the conditions where the outdoor metal-clad switchgear will be installed and operated.

B. Solar Radiation

The most important source of heat in outdoor-metal-enclosed switchgear, aside from electric losses within the gear itself, is the effect of solar radiation. The maximum possible radiation received at the earth's surface is known as the Solar Constant and is approximately 1.92 langleys (a langley is one gram calorie per square centimeter per minute) or 0.124 kilowatt per square foot. This magnitude of radiation can be closely approached only in dry, clean, desert air with the sun at its zenith. Records at Sante Fe, New Mexico show a magnitude of 1.64 langleys, and 1.72 langleys have been recorded at Mount Whitney, California. Tests made at State College, Pennsylvania and Columbus,

Ohio indicate that a maximum of approximately 1.5 langleys is reached at these locations, and that this varies from zero at sunrise approximately sinusoidally to a maximum at noon (solar time) and diminishes to zero before sunset. The figure of 1.5 langleys has been chosen as a practical value which is representative of the areas in which the majority of outdoor metal-enclosed switchgear will be installed. This value of external radiation was used in indoor testing where the source of external energy was banks of infrared lamps. These lamps were the only practical source of radiated heat for indoor testing. However, they represent only a portion of the spectrum of the radiation received from the sun, and therefore are not an entirely satisfactory equivalent.

Figure 1 shows the measured radiation at two locations and also a curve indicating what this radiation would be if the increase and decrease during the day were exactly sinusoidal.

Since the sun was at the Tropic of Cancer during the last two weeks of June, when these measurements were taken, there is also a horizontal component of radiation of approximately 0.45 langley at 40 degrees North latitude which would affect a vertical surface with a southern exposure. This additional source of heat was taken into account during indoor tests.

The average radiation at State College, Pennsylvania and Columbus, Ohio was considerably below these maximum figures for the two-week period for which the records were kept. However, in other localities, particularly in the West, full values of radiation may be an almost daily occurrence in the summer.

On the basis of the laboratory and field test data as well as calculated data which were accumulated during this study on outdoor metal-clad switchgear, it was established that the maximum temperature rise of the conducting parts due to solar radiation alone is about 15C (27F).

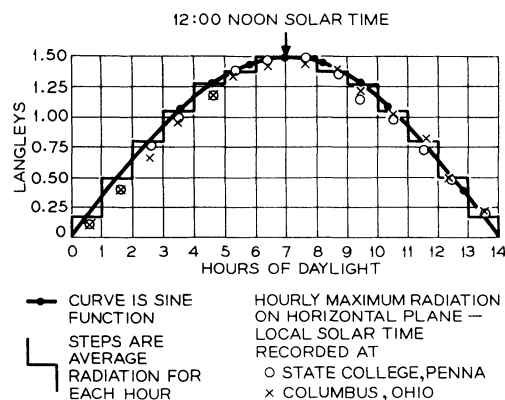


Figure 1—Relation between recorded data for solar radiation on a horizontal surface and a sine function curve. Radiation values are hourly maximums for July 16-30, 1952 period as recorded by the U. S. Weather Bureau. One langley = One gram calorie per square centimeter per minute. = 64.7 watts/sq. ft.

C. Wind Influence

It is estimated a 10-mile-per-hour wind would totally offset the heating effect of the noon-day sun. However,

switchgear structures vary so much in shape and relative amount of exposed surface that no accurate figure can be given. The effect of air movement as low as three miles per hour would be significant, and values in this range are recognized as having a cooling effect on transmission line conductors. However, since there may be localities where the wind velocity is very low and no accurate data are available, it is recommended that no consideration be given to the effect of wind in cooling switchgear.

VENTILATION

Ventilation of outdoor switchgear is usually more restricted than that for indoor gear because it is desirable to provide filters to exclude airborne dust and dirt. It is not desirable to seal switchgear units tightly because moisture condensation may occur on the electric parts and insulation. Some form of heat is also necessary to keep the internal air above the dew point. Electric losses when appreciable loads are being carried on the circuits would usually be adequate, but the automatic means required to recognize this source of heat and turn off the heaters have seldom been used. The majority of outdoor switchgear units are equipped with heaters under manual control. However, thermostats, humidistats, and differential thermostats have all been used. Theoretically, the use of the latter is one of the better approaches to the problem, but differential thermostats operating on the small heat differential provided by the usual heater installation may not be entirely satisfactory or reliable. If heaters are used in the hotter parts of the country in the months when maximum temperatures are reached and the application requires that breakers be operated very near to full load, it may be desirable to use current-responsive relays to turn them off. This would result in two to three degree centigrade decrease in internal air temperature.

CURRENT-CARRYING CAPABILITIES OF SWITCHGEAR

The curves in Figure 2 were based on the test and calculated data previously mentioned which established that the maximum temperature rise of the conducting parts due to solar radiation alone was in the order of 15C (27F). The values given on the horizontal scale are not temperatures which can be measured at any particular time but are 30-year monthly normal maximum temperatures. The curves also take into account the maximum limits of observable temperature as established in American Standard C37.20-1955. These limits are based on the temperature rise above an ambient temperature of 40C (104F) outside the enclosure. Since solar radiation contributes a temperature rise of 15C (27F) to the conducting parts, it is necessary to start the derating at 25C (77F). At 40C (104F) monthly normal maximum temperature, the addition of the 15C (27F) temperature rise due to solar radiation would allow a temperature rise on the conductors of only 35C (63F). Therefore, the current-carrying capability of the switchgear is reduced to the value indicated on the curves.

For example, a 1200-ampere metal-clad switchgear equipment operating outdoors and exposed to the effect of a typical solar cycle of 1.5 langleys maximum amplitude