An American National Standard

IEEE Guide for Safety in AC Substation Grounding

1. Introduction

1.1 Purpose and Scope. The intent of this guide is to provide guidance and information pertinent to safe grounding practices in ac substation design. This guide is primarily concerned with outdoor substations, either conventional or gas-insulated. These include distribution, transmission, and generating plant substations. With proper caution, the methods described herein are also applicable to indoor portions of such substations, or to substations that are wholly indoors.[1]

The specific purposes of this guide are:

(1) To establish, as a basis for design, the safe limits of potential differences that can exist in a substation under fault conditions between points that can be contacted by the human body

(2) To review substation grounding practices with special reference to safety, and develop criteria for a safe design

(3) To provide a procedure for the design of practical grounding systems, based on these criteria

(4) To develop analytical methods as an aid in the understanding and solution of typical gradient problems

(5) To provide a bibliography of pertinent literature on grounding, and English translations of some of the more valuable foreign language articles

[1] Obviously, the same ground gradient problems that exist in a substation yard should not be present within a building. This will be true provided the floor surface either assures an effective insulation from earth potentials, or else is effectively equivalent to a conductive plate or close mesh grid that is always at substation ground potential, including the building structure and fixtures.

Therefore, even in a wholly indoor substation it may be essential to consider some of the possible hazards from perimeter gradients (at building entrances) and from transferred potentials described in Section 6. Furthermore, in the case of indoor gas-insulated facilities, the effect of circulating enclosure currents may be of concern, as discussed in Section 8.

The concept and use of safety criteria are described in Sections 1-6, practical aspects of designing a grounding system are covered in Sections 7-11, and procedures and evaluation techniques for the grounding system assessment (in terms of safety criteria) are described in Sections 12-18. Supporting material is organized in Appendixes A-J.

Some of the special hazards encountered in gas-insulated substations and techniques for analyzing these problems are discussed in Section 8 and Appendix D.

No attempt is made to cover the grounding problems peculiar to dc substations. A quantitative analysis of the effects of lightning surges is also beyond the scope of this guide. However, the listed references contain further information on both subjects.

A grounding system designed as recommended herein will, nonetheless, provide a high degree of protection against steep wave front surges entering the station and passing to earth through its ground electrodes.[2]

1.2 Relation to Other Standards. This guidc only briefly discusses the field tests required to evaluate soil resistivity. The procedures for measuring the resistance of the installed grounding system, the surface gradients, and the continuity of thc grid conductors are described in more detail in ANSI/IEEE Std 81-1983 [3].[3]

ANSI/IEEE Std 142-1982 [5] generally takes its recommended grounding practices from this guide. Also known as "The IEEE Green Book," it covers some of the practical aspects of grounding in more detail, such as equipment grounding, cable routing to avoid induced ground currents, cable sheath grounding, static and lightning protection, indoor installations, etc. However, as such, it refers to the previous edition of this guide.

IEEE Std 367-1979 [9] provides a detailed explanation of the asymmetrical current phenomenon and of the fault current division, which to a large degree parallels that given herein. Of course, the reader should be aware that the ground potential rise calculated for the purpose of telecommunication protection and relaying applications is based on a somewhat different set of assumptions concerning the maximum grid current, in comparison with those used for the purposes of this guide.

Finally, a guide that is presently being developed by the IEEE Power Generation Committee's Working Group on Generator Station Grounding Practices will give more detailed information on specific generating plant grounding problems. These include stack and cooling tower grounding, building grounds, etc. See 1.5.

1.3 Key Definitions. Most of the definitions given herein pertain solely to the applications of this guide, though those approved or standardized by other bodies

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[2] The greater impedance offered to steep front surges will somewhat increase the voltage drop in ground leads to the grid system, and decrease the effectiveness of the more distant parts of the grid. Offsetting this in large degree is the fact that the human body apparently can tolerate far greater current magnitudes in the case of lightning surges than in the case of 50 or 60 Hz currents.

[3] The numbers in brackets correspond to those of the references listed in 1.4.

are used whenever possible. No further reference will be made to any of the key definitons stated below, unless necessary for clarity. All other definitions are placed within the text of individual sections. An alphabetical index of all definitions used is given in Appendix F. For additional definitions refer to ANSI/IEEE Std 100-1984 [4].

In spite of the fact that grounding concepts are generally well understood, some design solutions are more a reflection of a routine rather than of a well-conceived design approach. For this reason, the following point is made prior to the first definition: No ground current or ground fault current will flow into the earth unless at least one ground return circuit exists. This return circuit enables the current produced by a source, however distant, to return through the earth to that source. The definition of a *ground return circuit* is primary, and all other *ground* related definitions are secondary, following from it.

ground return circuit. A circuit in which the earth or an equivalent conducting body is utilized to complete the circuit and allow current circulation from or to its current source.

ground. A conducting connection, whether intentional or accidental, by which an electric circuit or equipment is connected to the earth or to some conducting body of relatively large extent that serves in place of the earth.

grounded. A system, circuit, or apparatus referred to is provided with ground for the purposes of establishing a ground return circuit and for maintaining its potential at approximately the potential of earth.

ground current. A current flowing into or out of the earth or its equivalent serving as a ground.

initial symmetrical ground fault current. The maximum rms value of symmetrical fault current after the instant of a ground fault initiation. As such, it represents the rms value of the symmetrical component in the first half-cycle of a current wave that develops after the instant of fault at time zero. Generally,

$$I_{f(0+)} = 3I''_0 \qquad \text{(Eq 1)}$$

where

$I_{f(0+)}$ = initial symmetrical ground fault current

I''_0 = rms value of zero-sequence symmetrical current that develops immediately after the instant of fault initiation, that is, reflecting the subtransient reactances of rotating machines contributing to the fault

NOTE: Elsewhere in the guide, this initial symmetrical fault current is shown in an abbreviated notation, as I_f, or is referred to only as $3I_0$. The underlying reason for the latter notation is that, for purposes of this guide, the initial symmetrical fault current is assumed to remain constant for the entire duration of the fault.

decrement factor. An adjustment factor used in conjunction with the initial symmetrical ground fault current parameter in safety-oriented grounding calculations. It allows us to obtain an rms equivalent of the asymmetrical current wave for a given fault duration, accounting for the effect of initial dc offset and its attenuation during the fault.

effective asymmetrical fault current. The rms value of asymmetrical current wave, integrated over the entire interval of fault duration. (See Fig 1.)

NOTE: In terms of this guide, it can be expressed as

$$I_F = D_f(t_f) I_f \qquad \text{(Eq 2)}$$

where

I_F = effective asymmetrical fault current in A
I_f = (initial) symmetrical ground fault current in A
$D_f(t_f)$ = decrement factor accounting for the effect of a dc offset during the subtransient period of fault current wave on an equivalent time basis of the entire fault duration, t_f, for t_f given in s

1.4 References. The following publications shall be used in conjunction with this standard.

[1] ANSI C2-1984, National Electrical Safety Code (note particularly Rule 93C).[4]

[2] ANSI/ASTM D448-80, Specifications for Standard Sizes of Coarse Aggregate for Highway Construction.[5]

[3] ANSI/IEEE Std 81-1983, IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System — Part I: Normal Measurements.

[4] ANSI/IEEE Std 100-1984, IEEE Standard Dictionary of Electrical and Electronics Terms.

[5] ANSI/IEEE Std 142-1982, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems.

[6] ANSI/IEEE Std 837-1984, IEEE Standard for Qualifying Permanent Connections Used in Substation Grounding.

[7] ANSI/IEEE C37.010-1979, IEEE Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

[8] ANSI/IEEE C57.12.00-1980, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power and Regulating Transformers.

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[4] ANSI publications are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY, 10018.

[5] ANSI/ASTM publications are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY, 10018 and the Sales Department, American Society of Testing and Materials, 1916 Race St, Philadelphia, PA 19103.

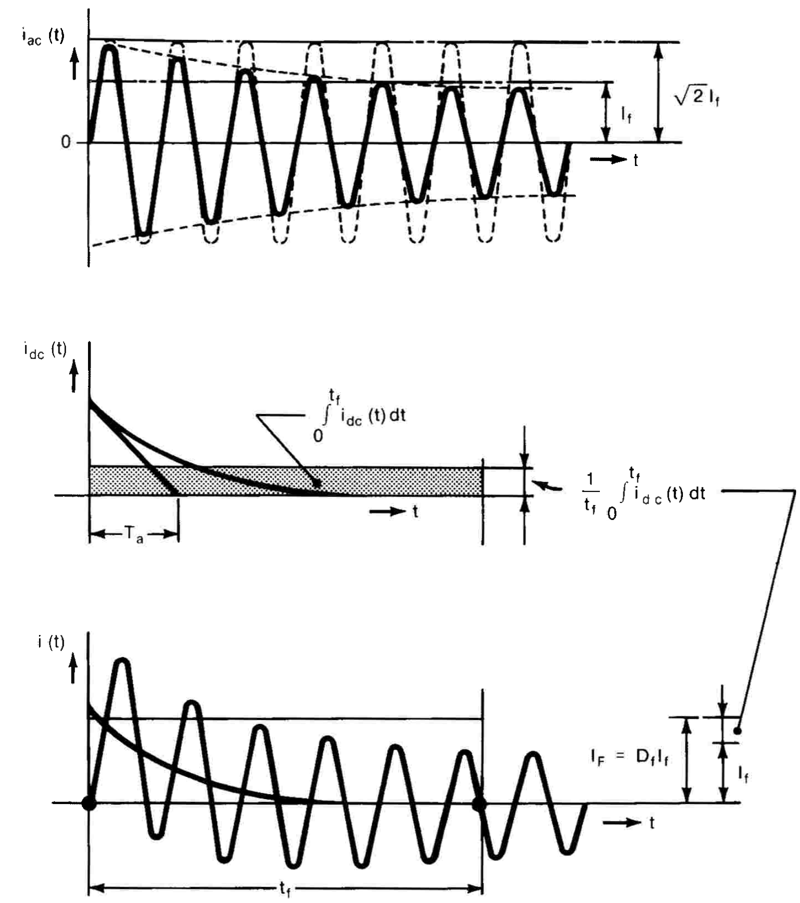

Fig 1
Relationship Between Actual Values of Fault Current and Values of I_F, I_f, and D_f for Fault Duration t_f

[9] IEEE Std 367-1979, IEEE Guide for the Maximum Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault.[6]

[10] IEEE Std 590-1977, IEEE Cable Plowing Guide.

[6] IEEE publications are available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, Piscataway, NJ 08854.