

An American National Standard

**IEEE Guide for
Generator Ground Protection**

Sponsor

**Power System Relaying Committee of the
IEEE Power Engineering Society**

Secretariat

**Institute of Electrical and Electronics Engineers, Inc
National Electrical Manufacturers Association**

Approved December 17, 1981

IEEE Standards Board

Approved February 4, 1983

American National Standards Institute

© Copyright 1985 by

**The Institute of Electrical and Electronics Engineers, Inc
345 East 47th Street, New York, NY 10017, USA**

*No part of this publication may be reproduced in any form,
in an electronic retrieval system or otherwise,
without the prior written permission of the publisher.*

IEEE Standards documents are developed within the Technical Committees of the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Board. Members of the committees serve voluntarily and without compensation. They are not necessarily members of the Institute. The standards developed within IEEE represent a consensus of the broad expertise on the subject within the Institute as well as those activities outside of IEEE which have expressed an interest in participating in the development of the standard.

Use of an IEEE Standard is wholly voluntary. The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE Standard is subjected to review at least once every five years for revision or reaffirmation. When a document is more than five years old, and has not been reaffirmed, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of all concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason IEEE and the members of its technical committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration.

Comments on standards and requests for interpretations should be addressed to:

Secretary, IEEE Standards Board
345 East 47th Street
New York, NY 10017
USA

Foreword

(This Foreword is not a part of ANSI/IEEE C37.101-1985, IEEE Guide for Generator Ground Protection.)

This guide was prepared by the Generator Ground Protection Working Group of the Rotating Machinery Subcommittee of the Power System Relaying Committee of the IEEE Power Engineering Society.

The Institute is indebted to those individuals who gave so freely of their time and contributed so willingly and cooperatively to this guide. Particular credit goes to K. Winick and G. Paradis, past Chairman of the working group, whose sustained efforts made this guide possible.

This guide is intended to enable one to determine the protection requirements for a specific application.

The Standards Committee on Power Switchgear, C37, which reviewed and approved this guide, had the following personnel at the time of approval:

C.L. Wagner, *Chairman*

John D. Hopkins, *Secretary*

J.E. Beehler, *Executive Vice-Chairman of High-Voltage Switchgear Standards*

W.E. Laubach, *Executive Vice-Chairman of Low-Voltage Switchgear Standards*

S.H. Telender, *Executive Vice-Chairman of IEC Activities*

<i>Organization Represented</i>	<i>Name of Representative</i>
Association of American Railroads	<i>Vacant</i>
Association of Iron and Steel Engineers	J.M. Tillman
Electric Light and Power Group	K.G. Adgate
	J.E. Beehler
	R.L. Capra (<i>Alt</i>)
	H.G. Darron
	H.F. Frus
	K.D. Hendrix
	R.L. Lindsey (<i>Alt</i>)
	E.E. Ramm (<i>Alt</i>)
	F.R. Solis
Institute of Electrical and Electronics Engineers	M.J. Beachy (<i>Alt</i>)
	R.N. Bell (<i>Alt</i>)
	H.H. Fahnoe
	R.E. Friedrich
	M.J. Maier
	C.A. Mathews (<i>Alt</i>)
	D.C. Musgrave (<i>Alt</i>)
	G.W. Walsh
	H.F. White
National Electrical Manufacturers Association	A.P. Colaiaco
	R.W. Dunham
	D.G. Portman
	G.A. Wilson
	W.R. Wilson
Tennessee Valley Authority	Robert C. St. Clair
Testing Laboratory Group	L. Frier
	E.J. Huber
	R.W. Seelbach (<i>Alt</i>)
US Department of the Army	Robert H. Bruck
US Department of the Interior, Bureau of Reclamation	Edward M. Tomsic
US Department of Defense, Defense Communications Agency	<i>Vacant</i>
US Department of the Navy, Naval Facilities Engineering Command	D.M. Hannemann

At the time this guide was approved the members of the Generator Ground Protection Working Group were as follows:

A.C. Pierce, *Chairman*

H. DiSante
E.J. Emmerling

C.H. Griffin
C.L. Wagner

At the time this guide was approved, the members of the Rotating Machinery Protection Subcommittee were as follows:

R.F. Archart, *Chairman*
G.R. Nail, *Vice Chairman/Secretary*

M.S. Baldwin	J.A. Imhof	A.C. Pierce
F.G. Basso	L.E. Landoll*	C.M. Shuster
J. Berdy	J.R. Latham	W.H. VanZee
J.L. Blackburn	N.E. Nilsson**	F. VonRoeschlaub
B. Bozoki	G.C. Parr	C.L. Wagner†
E.J. Emmerling	C.J. Pencinger	J.E. Waldron
R.J. Fernandez		R.C. Zaklukiewicz

*Liaison to Rotating Machinery Committee
**Liaison from Rotating Machinery Committee
†Liaison to Power Generation Committee

When the IEEE Standards Board approved this guide on December 17, 1981 it had the following membership:

Irvin N. Howell, Jr, *Chairman*

Irving Kolodny, *Vice Chairman*

Sava I. Sherr, *Secretary*

G.Y.R. Allen	Jay Forster	Frank Rosa
J.J. Archambault	Kurt Greene	Robert W. Seelbach
James H. Beall	Loering M. Johnson	Jay A. Stewart
John T. Boettger	Joseph L. Koepfinger	William E. Vannah
Edward Chelotti	John E. May	Virginus N. Vaughan, Jr
Edward J. Cohen	Donald T. Michael*	Art Wall
Len S. Corey	John P. Riganati	Robert E. Weiler

*Member emeritus

Contents

SECTION	PAGE
1. Introduction	7
2. References	7
3. Summary of Protection Schemes	7
4. Generator Connections	10
5. Grounding Methods	11
5.1 Method I, Distribution-Transformer Grounded (High Resistance).....	12
5.2 Method II, Neutral-Resistor Grounded (High Resistance)	12
5.3 Method III, Neutral-Resistor Grounded (Low Resistance).....	12
5.4 Method IV, Neutral-Reactor Grounded (Low Inductive Reactance)	12
5.5 Method V, Ground-Fault Neutralizer Grounded (Tuned Inductive Reactor).....	12
5.6 Method VI, Grounding Transformer Grounded (High Resistance)	12
5.7 Method VII, Grounding Transformer Grounded (Medium Resistance)	13
5.8 Method VIII, Ungrounded	13
6. Protective Schemes	13
6.1 Scheme 1, Ground Overvoltage—Complete Shutdown	14
6.2 Scheme 2, Ground Overvoltage—Permissive Shutdown	15
6.3 Scheme 3, Ground Overvoltage—Alarm and Time-Delay Shutdown	16
6.4 Scheme 4, Ground Overvoltage—Alarm	16
6.5 Scheme 5S, Startup Ground Overvoltage—Complete Shutdown	16
6.6 Scheme 6, Ground-Fault Neutralizer Overvoltage—Alarm and Time-Delay Orderly Shutdown	17
6.7 Scheme 7, Wye-Broken-Delta Voltage Transformer (VT), Ground Overvoltage—Complete Shutdown	18
6.8 Scheme 8S, Startup Wye-Broken Delta Voltage Transformer (VT), Ground Overvoltage—Complete Shutdown	19
6.9 Scheme 9, Secondary Connected Current Transformer (ct), Time-Delay Ground Overcurrent—Complete Shutdown	19
6.10 Scheme 10, Primary Connected Current Transformer (ct), Time-Delay Ground Overcurrent—Complete Shutdown	20
6.11 Scheme 11, Instantaneous Ground Overcurrent—Alarm or Complete Shutdown, or Both	20
6.12 Scheme 12, Generator Leads Ground Overcurrent—Complete Shutdown.....	21
6.13 Scheme 13, 3-Wire Generator Leads Window Current Transformer (ct), Instantaneous Ground Overcurrent—Complete Shutdown	22
6.14 Scheme 14, 4-Wire Generator Leads Window Current Transformer (ct), Instantaneous Ground Overcurrent—Complete Shutdown	23
6.15 Scheme 15, Generator Percentage Differential—Complete Shutdown.....	23
6.16 Scheme 16, Generator Percentage Differential and Polarized Neutral Overcurrent—Complete Shutdown	23
6.17 Scheme 17, Delta-Connected Generator, Generator Percentage Differential—Complete Shutdown	24
7. Protective Device Function Numbers	25
FIGURES	
Fig 1 Scheme 1, Ground Overvoltage—Complete Shutdown.....	14
Fig 2 Scheme 2, Ground Overvoltage—Permissive Shutdown	16
Fig 3 Scheme 3, Ground Overvoltage—Alarm and Time-Delay Shutdown	16

SECTION	PAGE
Fig 4 Scheme 4, Ground Overvoltage—Alarm	16
Fig 5 Scheme 5S, Startup Ground Overvoltage—Complete Shutdown	17
Fig 6 Scheme 6, Ground-Fault Neutralizer Overvoltage—Alarm and Time-Delay Orderly Shutdown	17
Fig 7 Scheme 7, Wye-Broken-Delta VT, Ground Overvoltage—Complete Shutdown	18
Fig 8 Scheme 8S, Startup Wye-Broken-Delta VT, Ground Overvoltage—Complete Shutdown	19
Fig 9 Scheme 9, Secondary Connected ct, Time-Delay Ground Overcurrent— Complete Shutdown	19
Fig 10 Scheme 10, Primary Connected ct, Time-Delay Ground Overcurrent— Complete Shutdown	20
Fig 11 Scheme 11, Instantaneous Ground Overcurrent—Alarm or Complete Shutdown, or Both	21
Fig 12 Scheme 12, Generator Leads Ground Overcurrent—Complete Shutdown	21
Fig 13 Scheme 13, 3-Wire Generator Leads Window ct, Instantaneous Ground Overcurrent—Complete Shutdown	22
Fig 14 Scheme 14, 4-Wire Generator Leads Window ct, Instantaneous Ground Overcurrent—Complete Shutdown	23
Fig 15 Scheme 15, Generator Percentage Differential—Complete Shutdown	24
Fig 16 Scheme 16, Generator Percentage Differential and Polarized Neutral Overcurrent—Complete Shutdown	24
Fig 17 Scheme 17, Delta-Connected Generator, Generator Percentage Differential— Complete Shutdown	25

TABLE

Table 1. Generator Connections, Generator Grounding Methods, and Protective Scheme Numbers	8
---	---

APPENDIXES

Appendix A Generator-Ground Protection; Other Practices	27
Appendix B Generator Ground Protection Examples	33
Appendix C Bibliography	42

APPENDIX FIGURES

Fig A1 Scheme A, 3rd Harmonic Neutral Voltage	28
Fig A2 Scheme B, 3rd Harmonic Terminal to Ground Residual Voltage	29
Fig A3 Scheme C, 3rd Harmonic Ratio Differential Quantities	30
Fig A4 Scheme D, Neutral or Residual Voltage Injection	30
Fig A5 Scheme E, High-Impedance Generator Differential for Phase or Ground Faults	31
Fig A6 Scheme F, Residual High-Impedance Generator Differential	32
Fig A7 Scheme G, Residual High-Impedance Generator Differential and Generator Percentage Differential	32
Fig B1 Typical Generator Ground Protection One Line Diagram	33
Fig B2 Phase to Ground-Fault Symmetrical Component Equivalent Circuits	34
Fig B3 Phase to Ground-Fault Capacitive Reactance Equivalent Circuits and Phasor Diagrams	36
Fig B4 Relay and Fuse Coordination Curves	40

An American National Standard

IEEE Guide for Generator Ground Protection

1. Introduction

This guide has been prepared to aid in the application of relays and relaying schemes for the protection of synchronous generators for single-phase-to-ground faults in the stator winding. The guide is not intended for the selection of generator or ground connection schemes.

The information included in the main body is limited to those generator connections, grounding practices, and protective schemes generally used in North America.

Appendix A provides information on some of the protective schemes in use elsewhere in the world and on schemes which are not in widespread use throughout North America.

Appendix B provides examples of how to calculate ground overcurrent and overvoltage relay settings for the various protective schemes and how to coordinate them with voltage transformer secondary fuses.

Appendix C is a bibliography of available literature on the ground-fault problem from which source material was drawn.

Recommended protective schemes and the arrangements in which they may be applied are indicated in Table 1. The use of this table is described in Section 3 with supporting information provided in subsequent sections.

2. References

When the following standards are superseded by an approved revision, the latest revision shall apply.

[1] ANSI/IEEE C37.2-1979, IEEE Standard Electrical Power System Device Function Numbers.

[2] IEEE Std 143-1954, IEEE Application Guides for Ground-Fault Neutralizers, Grounding of Synchronous Generator Systems, Neutral Grounding of Transmission Systems.

[3] GROSS, E.T.B. Sensitive Generator Ground-Fault Protection, *Proceedings American Power Conference*, vol 36, 1974, pp 1031-1035.

[4] GROSS, E.T.B., and GULACHENSKI, E.M. Experience of the New England System with Generator Protection by Resonant Neutral Grounding. *IEEE Transactions on Power Apparatus and Systems*, vol 92, Jul/Aug, 1973, pp 1186-1194.

[5] IEEE COMMITTEE REPORT. Potential Transformer Application on Unit Connected Generators. *IEEE Transactions on Power Apparatus and Systems*, vol 91, Jan/Feb 1972, pp 24-28.

3. Summary of Protection Schemes

A summary of recommended protective schemes is given in Table 1, which is a matrix of generator connections, generator grounding methods, and the scheme numbers which identify the protective schemes. The following explanation has been prepared as an aid for its use.

Across the top of the table, heading the six columns (A-F), are one-line diagrams covering most, if not all, of the significant variations of generator-transformer-bus circuit-breaker arrangements that might be encountered in a present-day electric utility or industrial power system. These diagrams are discussed in Section 4 of this guide. Vertically, along the left

side of the table, heading the eight rows (I–VIII), are one-line diagrams of approved grounding methods for electric generators covered in IEEE Std 143-1954 [2].¹ These diagrams will be explained and discussed subsequently. The individual boxes in Table 1 list by scheme number (1, 2, 3, etc), the different applicable ground-fault protective schemes that apply for a given generator connection, and a given grounding method. For example, the box under column E and row III indicates that protective schemes 10, 11, 14, 15, and 16 may be applied for single-phase-to-ground fault protection of a wye-connected generator. The neutral is grounded through a *low* resistance, and the main leads are connected directly to a grounded system through a circuit breaker.

Those boxes which are crossed out and contain no protection scheme numbers represent cases that are either not practical or not recommended. For example, under column D, a delta-connected generator has no neutral available, so boxes under column D (associated with rows I, II, III, IV, and V) are crossed out. Also, the box under column E (and associated with row V) is crossed out because the use of a tuned-resonant grounding method, in the neutral of a wye-connected generator directly connected to a grounded system, is a misapplication.

The protective scheme numbers in the boxes refer to protective schemes that are completely illustrated and described in Section 6 of this guide. In some boxes, there are some numbers that are followed by the suffix S, such as 5S in box (D–VI). The suffix S indicates that the protective scheme represented by that scheme number designation is suitable for use only when the machine is running and disconnected from the system, but with field excitation applied. This type of protection utilizes protective devices that are not tuned to normal system frequency, so that they offer sensitive protection over a wide range of frequencies. Thus, schemes designated with the suffix S are suitable for the protection of machines during startup and shutdown. Protective scheme numbers without the suffix S represent schemes that are indexed to provide protection only during operation at rated frequency. For

example, in the case of the generator connection illustrated in the diagram of column A with the grounding connection of row I, scheme 8S is intended to detect any single-phase-to-ground fault in the generator or its leads during startup or shutdown procedures while field excitation is applied, but with the main circuit breaker open. In the box (D–VIII) the protective scheme represented by scheme 17 is intended for protection during the time that the main breaker is closed and the machine is running normally. In general, startup and shutdown protection for single-phase-to-ground faults is indicated only in those applications where a high-impedance grounded or an ungrounded generator is connected directly to a grounded system, or where excitation is applied to a machine early in the startup cycle or is removed late in the shutdown cycle. This startup and shutdown protection is generally not intended to coordinate properly with system protection. For this reason, it should be removed from service at the time the unit is synchronized to the system. This is usually performed automatically when the main breaker is closed.

The protective scheme numbers in Table 1 are arranged in the boxes with the running protective schemes listed first, and the startup protective schemes—where they apply—listed last. Within each box, the schemes within the brackets are the most widely used and recommended. The remainder of the schemes are listed in numerical sequence.

It should be recognized that the bracketed recommendations are based on the anticipated performance of the schemes and not on other factors that might relate to the integrity of the generator itself. For example, while schemes 1 and 7 in box (A–I) could provide essentially the same order of protection for generator single-phase-to-ground faults, the fact that scheme 7 requires voltage transformers on the generator leads may reduce the overall reliability of the generator. Thus, scheme 1 might be more desirable than scheme 7, but they are both indicated in the table to have the same order of merit as far as the protection afforded for single-phase-to-ground faults is concerned.

No attempt is made in Table 1 to indicate primary or backup schemes. It is suggested that descriptions of all schemes applicable to a given situation be considered, and, unless overriding circumstances dictate otherwise, that one of

¹The numbers in brackets correspond to the references listed in Section 2 of this guide.

the bracketed schemes be used for the primary protection, and another high-rated scheme be used for backup or alternate protection.

The generator connections illustrated in column F are very similar to those in column A. The difference is only in the use of low-side circuit breakers in the diagram of column F. A comparison of the applicable protective schemes between columns A and F will indicate that they are nearly all the same. Because of the low-side circuit breakers in the diagrams of column F, field excitation might normally be applied to the unit when it is turning at, or very near to, rated frequency. Under these conditions, the need for startup or shutdown protection is minimized.

Section 5 describes grounding methods I–VIII. The different grounding methods head up the rows in Table 1 along the left-hand side. The diagrams in the column are intended to indicate the different grounding methods and the means for interfacing with the protective relay schemes. The diagrams in row I have both a neutral point N and a ground point in the primary circuit, as do those in rows II–V. The point N in the grounding method diagram connects to the point N in the generator-connection diagram with which it is applied. For example, if any grounding method, I–V, is used with any generator connection illustrated in columns A, B, E, or F, the generator neutral N in question is grounded through the neutral connection shown in the grounding method diagram. In the case of the delta-connected machines of columns C and D, no neutral point exists, so grounding method VI or VII should be used. This includes a wye-broken delta-connected distribution-transformer bank with a secondary resistor. The wye (Y) windings are connected to the associated-generator main leads. Finally, row VIII indicates an ungrounded machine which is grounded only through the system to which it may be connected.

In Table 1, the diagram for grounding methods also indicates the interface between the primary circuits and the protective schemes. An example of this is that grounding method I shows a distribution transformer with a secondary resistor. In series with the secondary of the distribution transformer is a current-transformer primary winding. The secondary winding of this current transformer terminates at terminals labeled R and S. A current-operated relay, connected to these two terminals, will

measure the current in the resistor during a ground fault in the generator stator or its associated circuits.

In this same diagram, terminals designated X and Y are connected across the resistor. If the operating coil of a voltage relay is connected to these terminals, it will measure the voltage developed across the resistor (which is proportional to the current through the resistor) during ground faults in the generator-stator winding or its associated circuits.

Again, in grounding method I, the current transformer in the neutral lead of the generator ground connection (in series with the primary winding of the distribution transformer) has its secondary winding terminating at points W and Z. A current-operated relay, connected to these terminals, will measure the current in the generator neutral during ground faults in the generator-stator winding or its associated circuits. The terminal points R, S, X, Y, W, and Z are the interface connections to the protective schemes. The same is true in grounding methods II–VI. Reference to these connections will show that not all the grounding methods provide the same opportunities for protection. For example, in method IV, only a neutral-current transformer is indicated with secondary connections to terminals W and Z.

The diagrams for each of the protective schemes in Section 6 indicate to which terminal points (R, S, W, etc) they connect. For example, protective scheme 1 will be found to have input connections labeled X and Y. This indicates that protective scheme 1 is always connected to terminals X and Y, regardless of the grounding method with which it is used. From Table 1, it will be noted that protective scheme 1 may be used with grounding methods I, II, and VI, since all of these have interfacing terminals labeled X and Y. Similar comments apply to the other protective schemes and the interfacing terminal designations.

4. Generator Connections

The six different classes of generator connections illustrated in Table 1 are intended to be representative of connections in common use today. While the connections of the two diagrams in column A are different, the arrangements are such that the same protective schemes

may be applied to both. The criteria here is that a single-phase-to-ground fault in a generator will not produce any significant zero-sequence current or voltages in the system, nor will a similar fault in the system produce any significant zero-sequence quantities in the generator circuit.

In connection A, if two units are paralleled on one transformer delta winding (as in the case of a cross compound machine, or machines with two-stator windings per phase), the same kind of protective schemes could be used as if only one unit were connected to the transformer. In general, for these applications, only one neutral is grounded. Where machines are connected to separate low-voltage transformer windings, each unit is grounded separately and has its own protective scheme. If tripping is employed, each protective scheme should initiate shutdown of all generators connected to a common transformer.

The generator connections of column B indicate that the unit stepup transformer is any autotransformer, with either a wound-delta tertiary or a phantom tertiary. In either case, the autotransformer provides a direct zero-sequence connection between the generator and the system so that the system grounding will provide zero-sequence current for ground faults in the generator. Also, the generator will provide zero-sequence current for faults on the system.

It is important to recognize in connection B that the wound or phantom tertiary of the main transformer will be a source of ground-fault current for generator faults. With this arrangement, even with the generator-neutral ungrounded and the main circuit breaker open, substantial fault current could flow for a ground fault in the stator when the generator is running with field excitation applied.

Connection C is similar to A, except that the generator(s) is connected in delta (Δ) rather than in wye (Y). Here, as in connection A, the delta-connected winding of the power transformer provides zero-sequence isolation between the generator and the system. Such delta-connected generator units have no neutral available, so that grounding is obtained by the use of a scheme as illustrated in Table 1, method VI. In general, one common grounding equipment is employed regardless of the number of generator units that are connected to a given transformer winding.

The circuit arrangements of connection D and E indicate generators connected directly to the system bus without any interposing stepup transformer. In general, these will be relatively small generators and they will be connected to a grounded (in contrast to an ungrounded) power system. As indicated in Table 1, the delta machine of connection D requires the scheme of method VI or VII for grounding while that of connection E uses a suitable neutral grounding method. In these applications, each machine has individual protection.

The circuit arrangements in the diagrams of connection F are the same as those in A, except that the former utilize individual generator circuit breakers on the low side of the power-transformer banks. Here again, the delta-wye (Δ -Y) connections of the transformers provide zero-sequence isolation between the generators and the system. In general, each generator will have individual grounding and protection. While the low-side circuit breakers permit switching of individual generators, the protective schemes available cannot distinguish between faults in the different generators connected to a common delta winding. However, if different time delay settings are utilized on the individual ground relays, the units will be sequentially tripped until the fault is cleared. This will establish the fault location. For this reason, a fault in any one machine may result in the loss of all generators connected to a common delta winding.

5. Grounding Methods

This guide describes protection for six of the seven grounding categories covered in IEEE Std 143-1954 [2]. The seven categories described in IEEE Std 143-1954 [2] are: solid, resistor, reactor, distribution transformer, ground-fault neutralizer, grounding transformer, and ungrounded. Protection for solidly grounded generators is not considered in this guide. These machines can be protected for ground faults by conventional differential and overcurrent relays. IEEE Std 143-1954 [2] considers high-, medium-, and low-resistance grounding as a single category. This guide lists them as separate grounding methods, since each requires a different type of protective scheme. Thus there are eight grounding methods given in Table 1. They are

- I Distribution-Transformer Grounded (High Resistance)
- II Neutral-Resistor Grounded (High Resistance)
- III Neutral-Resistor Grounded (Low Resistance)
- IV Neutral-Reactor Grounded (Low Inductive Reactance)
- V Ground-Fault Neutralizer Grounded (Tuned Inductive Reactor)
- VI Grounding-Transformer Grounded (High Resistance)
- VII Grounding-Transformer Grounded (Medium Resistance)
- VIII Ungrounded

5.1 Method I, Distribution-Transformer Grounded (High Resistance). Grounding Method I utilizes a distribution transformer with a primary-voltage rating equal to, or greater than, the line-to-neutral voltage rating of the generator, with a secondary rating of 120 V or 240 V. The distribution transformer should have sufficient overvoltage capability so that it does not saturate on phase-to-ground faults with the machine operated at 105% rated voltage. Secondary resistors are usually selected so that for a single-phase-to-ground fault at the terminals of the generator, the power dissipated in the resistor is equal to, or greater than, the zero-sequence reactive voltampere loss in the zero-sequence capacitance of the generator windings, its leads, and the windings of the transformers that are connected to the generator terminals. This arrangement is considered to be high-resistance grounding, and it limits the maximum single-phase-to-ground fault current to a value in the range of approximately 3–25 primary amperes. This is not of sufficient magnitude to operate standard generator differential relays. In general, the W–Z current transformer will have a ratio of unity and the R–S current-transformer ratio is usually selected so that its secondary current will be approximately equal to the primary current in the generator neutral.

5.2 Method II, Neutral-Resistor Grounded (High Resistance). Grounding Method II is functionally equivalent to that of Method I. In Method II, the resistor is sized directly to limit the single-phase-to-ground fault current to the same magnitude as in Method I, without the use of a distribution transformer. However, the volt-

age transformer voltage ratings are selected on the same basis as those for the distribution transformer in Method I. The W–Z current-transformer ratio is generally selected to be unity.

5.3 Method III, Neutral-Resistor Grounded (Low Resistance). Method III illustrates a low-resistance grounding arrangement. This type of grounding method permits fault current many times higher than those produced by methods I and II. In the case of the low-resistance grounding methods, the single-phase-to-ground fault current is high enough to operate the standard generator differential relays for faults in the stator, except for those near the neutral end of the machine.

5.4 Method IV, Neutral-Reactor Grounded (Low Inductive Reactance). Method IV illustrates a low inductive-reactance grounding arrangement. This type of grounding method permits fault current many times higher than those produced by Methods I and II. In the case of low inductive-reactance grounding methods, the single-phase-to-ground fault current is high enough to operate the standard generator differential relays for faults in the stator, except for those near the neutral end of the machine.

5.5 Method V, Ground-Fault Neutralizer Grounded (Tuned Inductive Reactor). Method V illustrates the ground-fault neutralizer arrangement. In this grounding method, a distribution type transformer with a ratio selected, as in Method I, is used with a secondary reactor. The ohmic value of this secondary reactor is selected so that, when reflected into the primary circuit, its reactance is equal to $\frac{1}{3}$ of the zero-sequence capacitive reactance of the circuit from (and including) the generator, to (and including) the delta windings of the associated power transformers. This type of grounding limits the single-phase-to-ground fault current to values that will not sustain an arc. It is applicable only where the zero-sequence capacitance of the circuit does not change significantly for different system conditions. Thus, it may not be readily applied to units arranged as in Fig F, such as when low-side breakers are applied.

5.6 Method VI, Grounding Transformer Grounded (High Resistance). Grounding Method VI uses three distribution transformers with

ratios selected as in Method I. The primary windings of these are connected to the generator leads in Y, while the secondaries are connected in broken Δ with a resistor. As in the case of Method I, the resistor is selected so that, for a single-phase-to-ground fault at the terminals of the generator, the power dissipated in the resistor is equal to, or greater than, the 3-phase zero-sequence reactive voltampere loss in the zero-sequence capacitance of the generator windings, its leads, and the windings of the transformers connected to the generator terminals. This grounding method is used on Δ -connected generators.

5.7 Method VII, Grounding Transformer Grounded (Medium Resistance). Grounding Method VII uses either a zig-zag transformer or a Y- Δ transformer. The primary windings of these are connected to the generator leads, with a resistor connected from the transformer neutral to ground. The effective grounding impedance is selected to provide sufficient current for selective ground relaying.

5.8 Method VIII, Ungrounded. Finally, if no grounding of any sort is employed on the leads or neutral of the generator, this is termed *ungrounded* and is noted in row VIII.

In grounding Methods I-V, the neutral-current transformer is shown to be connected between the fault-limiting device and ground. This current transformer could be located on either side of the fault-limiting device, depending on the preference of the user. The insulation level of the current transformer should be compatible with the possible voltage to which it may be exposed.

6. Protective Schemes

The protective schemes listed by number in Table 1 are illustrated and described in the following pages. The electrical characteristics of the relays represented by the device function numbers in the figures illustrating each scheme are defined in Section 7.

The methods employed for grounding and fusing the secondary circuits of voltage transformers and the methods for grounding current-transformer secondary circuits are not generally the same for all installations. For this reason no secondary fuses or ground points are indicated in the illustrated figures. However, all current

and voltage transformer secondary circuits should be grounded in a way that is consistent with accepted practices for personnel safety.

Protective schemes that are used to protect generators employing high resistance and resonant grounding methods (grounding methods I, II, V, and VI) are generally sensitive enough to detect phase-to-ground faults in the secondary, and in the primary circuits of voltage transformers connected to the generator leads. If the wye-connected secondary circuit of these voltage transformers is grounded at one of the phase leads, rather than at the neutral point, and if the neutral point is not wired out, the possibility of a phase-to-neutral fault is extremely remote. If this is the case, the relays employed in these protective schemes need not be coordinated with the voltage-transformer secondary fuses. However, coordination with the primary fuses is still required.

A complete discussion of voltage-transformer fusing is given in [5], Appendixes B3, and B4.

Usually, a generator is cleared without any intentional delay once the ground fault is detected. The risk of continuing operation with low-impedance grounding is extensive core damage, while the risk with high-impedance grounding is the possibility of a second fault.

The majority of existing generators having resonant-grounding methods are not tripped immediately, but an alarm is actuated and an orderly shutdown is started. Field experience of over 385 years with generators (prior to 1979) has shown no case of a second fault developing even though there have been at least seven ground faults, all of which were allowed to exist during a delayed tripping. See [3] and [4].

When immediate tripping is used, it includes the main and field circuit breakers, and the turbine stop valve or gates. Because a sudden, complete shedding of load can be a severe shock to the mechanical systems of the unit, including the steam system, it is sometimes necessary to employ an orderly shutdown rather than an immediate trip. In such cases, upon detection of a stator ground fault, the generator is either automatically or manually unloaded at a safe rate before tripping the circuit breakers. All the protective schemes that follow — except schemes 2, 3, 4, and 6 — indicate complete and immediate shutdown of the unit. Schemes 2, 3, and 4 illustrate three possible variations in the shutdown procedures