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IEEE Std C62.92.2™-1989 (R2005)

IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems Part II-Grounding of Synchronous Generator Systems

Sponsor

Surge Protective Devices Committee
of the
IEEE Power Engineering Society

Reaffirmed October 30, 2000

Approved October 13, 1989

American National Standards Institute

Reaffirmed June 9, 2005

Approved February 2, 1989

IEEE-SA Standards Board

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Foreword

(This Foreword is not a part of IEEE C62.92.2-1989, IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems, Part II—Grounding of Synchronous Generator Systems.)

This guide is the second in a series of documents on neutral grounding in electric utility systems. Part II covers the considerations and practices relating to the grounding of synchronous generator systems.

Emphasis in this guide is to be directed toward the grounding of synchronous generator systems in electric utility systems. Generator grounding practices used in industrial systems are covered in other guides and standards.

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IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems Part II—Grounding of Synchronous Generator Systems

1. Scope and References

1.1 Scope

This section summarizes the general considerations in grounding synchronous generator systems and discusses the factors to be considered in the selection of a grounding class and the application of grounding methods. The guidelines apply to both the large and small generators found in electric utility systems.

It should be borne in mind by the user that this report is intended solely as a guide. Statements are necessarily of a general nature and, therefore, do not take into account the requirements of special situations that can differ considerably from those discussed.

1.2 References

The following publications should be used in conjunction with this guide:

- [1] ANSI C50.10-1977, General Requirements for Synchronous Machines.¹
- [2] ANSI C50.12-1981, Requirements for Salient Pole Synchronous Generators and Generator/Motors for Hydraulic Turbine Applications.
- [3] ANSI C50.13-1977, Requirements for Cylindrical Rotor Synchronous Generators.
- [4] ANSI/IEEE C37.101-1985, Guide for Generator Ground Protection.²

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- [5] ANSI/IEEE C62.2-1987, Guide for Application of Gapped Silicon-Carbide Surge Arresters for Alternating Current Systems.
- [6] ANSI/IEEE C62.92-1987, Guide for the Application of Neutral Grounding in Electrical Utility Systems, Part I—Introduction.
- [7] ANSI/IEEE Std 95-1977 (R1982), Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Direct Voltage.
- [8] ANSI/IEEE Std 433-1974 (R1985), Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Voltage at Very Low Frequency.
- [9] ANSI/IEEE Std 519-1981, Guide for the Harmonic Control and Reactive Compensation of Static Power Converters.
- [10] ANSI/NFPA 70-1987, National Electrical Code.³
- [11] AIEE COMMITTEE REPORT. Relay Protection of A–C Generators. *AIEE Transactions on Power Apparatus and Systems*, vol PAS-70, 1951, pp 275–282.
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- [17] EATON, J. R., PECK, J. K., and DUNHAM, J. M. Experimental Studies of Arcing Faults on a 75kV Transmission System, *AIEE Transactions on Power Apparatus and Systems*, vol 50, 1931, pp 1467–1479.
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- [19] GROSS, E. T. B. “Sensitive Generator Ground Fault Protection,” *Proceedings of the American Power Conference*, vol 36, 1974, p 1034.
- [20] GROSS, E. T. B. and GULACHENSKI, E. M. Experience of the New England Electric System with Generator Protection by Resonant Neutral Grounding, *IEEE Transactions on Power Apparatus and Systems*, vol PAS-92, July/Aug 1973, pp 1186–1194.
- [21] GULACHENSKI, E. M. and COURVILLE, E. W. New England's 30 Years of Experience with Resonant Neutral Grounding of Unit-Connected Generators, *IEEE Transactions on Power Apparatus and Systems*, Sep 1984, pp 2572–2578.

³ NFPA documents are published by the National Fire Protection Association, Publications Sales Division, Batterymarch Park, Quincy, MA 02269. Copies are also available from the Sales Department of the American National Standards Institute, 1430 Broadway, New York, NY 10018.

[22] IEEE COMMITTEE REPORT. Potential Transformer Application on Unit-Connected Generators, *IEEE Transactions on Power Apparatus and Systems*, 1972, pp 24–28.⁴

[23] KHUNKHUN, K. J. S., KOEPFINGER, J. L., and HADDED, M. V. Resonant Grounding (Ground Fault Neutralizer) of a Unit Connected Generator. *IEEE Transactions on Power Apparatus and Systems*, vol PAS-96, no 2, Mar/Apr 1977, pp 550–559.

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[25] RAJK, M. N. Ground-Fault Protection of Unit-Connected Generators. *AIEE Transactions on Power Apparatus and Systems*, vol PAS-77, part III, 1958, pp 1082–1094.

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2. Objectives of Generator Grounding

The principle objective of grounding a synchronous generator system is the protection of the generator and associated equipment against damage caused by abnormal electrical conditions. The specific objectives in the protection of the generator are as follows:

- 1) Minimizing damage for internal ground faults.
- 2) Limiting mechanical stress in the generator for external ground faults.
- 3) Limiting TOVs (temporary overvoltages) and transient overvoltages on the generator insulation.
- 4) Providing a means of generator system ground fault detection.
- 5) Coordinating the protection of the generator with the requirements of other equipment connected at generator voltage level.

The choice of grounding class is largely determined by the relative importance to the user of each of the above objectives. The degree to which each of the possible grounding methods accomplishes the desired objectives is discussed in the following paragraphs.

2.1 Minimizing Damage for Internal Ground Faults

It has been concluded from field investigations of generator failures that limiting ground current magnitudes/durations during internal line-to-ground faults is no guarantee that core damage will be completely eliminated [11], [26].⁵ However, there is an indication that low-fault currents and fast-fault clearing will minimize core damage since iron burning and damage depend mainly on core current magnitude and duration. The energy generated in a fault is equal to $I^2 R_f t$, where R_f is the fault resistance. This relationship indicates that a reduction in current will have a greater reduction in fault-heating damage than a proportional reduction in time. However, the energy generated by an arcing fault will not be reduced by the square of the reduced current as implied by the equation. It will reduce more slowly because the arcing fault resistance is neither constant nor linear [25].

The available classes of grounding may be ranked as follows in approximate order of increasing fault current:

- 1) Resonant grounded
- 2) Ungrounded
- 3) High-resistance grounded

⁴ IEEE publications are available from IEEE Service Center, 445 Hoes Lane, Piscataway, NY 08855-1331.

⁵ The numbers in brackets correspond to those of the references listed in 1.2.

- 4) Low-resistance grounded
- 5) Low-inductance grounded
- 6) Effectively grounded

It should be noted that the ground-fault current depends not only on the generator grounding, but also on other sources of ground current available to the generator. The last three classes have substantially higher fault current levels than ungrounded, resonant grounded, and high-resistance grounded classes (see ANSI/IEEE C62.92-1987, Table 1 [6] for more information).

In addition to the normal shutdown sequence (eg, tripping the generator breaker and excitation) initiated by the machine protective relays, other measures are sometimes used to reduce the magnitude and duration of the fault current *after* the ground-fault relay has operated. These measures are (1) use of automatic neutral circuit breakers and (2) forced field reduction. Automatic neutral circuit breakers are used for comparatively small machines. When a neutral generator breaker is used, the Transient Recovery Voltage (TRV) characteristics of the breaker must be considered.

Where automatic neutral circuit breakers are applied, it is their function to interrupt heavy currents in a single phase-to-ground fault within the generators, thereby minimizing the damage. Opening of the neutral ground connection will change the system parameters of X_0/X_1 and R_0/X_1 and result in higher than normal temporary overvoltages on the unfaulted phases.

After the main circuit breaker has been tripped, the fault current will continue to flow as long as the fault circuit exists and until field flux in the generator decays to 0. Reduction of armature fault current can be accomplished with forced field reduction of the excitation system. Forced field reduction can be accomplished in several different ways [13]. The decay rate of the generator field flux determines the rate of reduction in generator fault current.

2.2 Limiting Mechanical Stress in the Generator for External Ground Faults

Fault current limiting devices are generally required for machines manufactured in accordance with the following standards:

ANSI C50.10-1977 [1]

ANSI C50.12-1981 [2]

ANSI C50.13-1977 [3]

Prior to these standards, no fault current limiting device was required in the generator neutral.

Meeting the limitation of ANSI C50.12-1981 [2] and ANSI C50.13-1977 [3] requires that at least a minimum value of impedance, either a resistance or a reactance, be installed in the neutral of all wye-connected grounded generators where the zero-sequence reactance is less than positive-sequence subtransient reactance.

In calculating the maximum currents that can flow in the generator windings during an external fault, it is usually sufficient to consider the generator impedances alone. It can be shown that, if sufficient neutral impedance is used to make the phase-to-ground fault current less than or equal to the 3-phase fault current with the machine isolated from the system, the winding currents for any fault will be less than or equal to the winding current for a 3-phase fault [14].

2.3 Limiting Overvoltages on Generator Insulation

The class of grounding affects generator overvoltage protection in controlling the magnitude of temporary and transient overvoltages during a ground fault and, consequently, determines the minimum rating of surge arresters that can be employed. These considerations are common to grounding all types of apparatus. The available classes of

grounding may be ranked as follows in order of increasing temporary overvoltages assuming a fault resistance that yields the highest coefficient of grounding but neglects the effects of restrikes within a solid dielectric [15]:

- 1) Effectively grounded
- 2) Low-inductance grounded
- 3) Low-resistance grounded
- 4) Resonant grounded
- 5) High-resistance grounded
- 6) Ungrounded

Ordering of transient overvoltages with grounding classes is difficult (refer to ANSI/IEEE C62.92-1987, Table 1 [6]). A comparison with the effect of grounding on fault current magnitude indicates that very low fault currents are generally obtained at the risk of higher temporary and transient overvoltages.

The insulation of all apparatus connected to the generator voltage system must withstand all temporary and transient overvoltages occurring as a result of unbalanced faults, switching, and lightning surges. Surge arresters, which may operate on transient overvoltages, should be applied so as to be able to withstand the temporary overvoltages that occur for unbalanced faults or other conditions. (Refer to ANSI/IEEE C62.92-1987, Table 1 [6], Class A and B. See also ANSI/IEEE C62.2-1987 [5].) It is, therefore, important when selecting a grounding class to consider the transient and temporary overvoltages that will result and the stresses on apparatus insulation and the protective margins possible with surge protective devices.

In any discussion of transient overvoltages, it should be recognized that numerous field tests have been made in an attempt to set up and measure high-transient voltages resulting from phase-to-ground arcing faults in air. From the results of these tests, it may be concluded that the conditions for building up these high voltages in an arc in air seldom exist [12], [17], [24]. However, it is suspected that intermittent faults through solid insulations may produce the necessary conditions for high-transient overvoltages. On the other hand, a system may have relatively high-transient overvoltages during switching operations if restriking occurs in the breaker. Accordingly, in considering any kind of grounding from the viewpoint of transient voltages, it is advisable to determine whether there will be switching to generator voltage at present or some time in the future.

The effect of grounding on the transient overvoltages following the occurrence and clearing of unbalanced faults at the generator terminals with and without restriking is illustrated in Figs 1 (a), 1 (b), and 2 [12], [17], [24]. The information presented in these figures was obtained from a Transient Network Analyzer (TNA) where clearing and restriking of the arc in a single phase-to-ground fault could be controlled to produce the maximum overvoltages. The system studied consisted of a generator model, with adjustable neutral grounding reactance, and a circuit breaker at generator voltage. The generator was simulated by a reactance of 1.28Ω per phase, at 60 Hz, a winding capacitance of $0.35 \mu\text{F}$ per phase, and a capacitance to ground on the terminals of the generator of $0.20 \mu\text{F}$ per phase. The neutral reactance was varied to give a range of ratios of X_0/X_1 . Results demonstrate the importance of selecting the proper class of neutral grounding in order to limit the transient overvoltages caused by switching surges.