



IEEE Guide for Generator Ground Protection

IEEE Power Engineering Society

Sponsored by the
Power System Relaying Committee



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

Approved 15 September 2006

IEEE-SA Standards Board

Abstract: The guide is intended to assist protection engineers in applying relays and relaying schemes for protection against stator ground faults on various generator grounding schemes. The existing guide is outdated due to rapid technology development. Hence, the revised guide includes new stator ground protection principles that have evolved with the use of new technologies in relay designs. Additional application examples are included, and other issues raised by the users are also addressed. The guide is not intended for the selection of generator or ground connection schemes.

Keywords: generator grounding method, grounding scheme, hybrid ground protection, subharmonic injection scheme

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Introduction

This introduction is not part of IEEE Std C37.101-2006, IEEE Guide for Generator Ground Protection.

IEEE Std C37.101 was initially published in 1981. It was subsequently revised in 1985 and 1993, and reaffirmed in 2000. The guide is designed for the ground protection of typical steam, hydraulic, and combustion-turbine generators. Any scheme that is judged to be a good alternative practice for generator ground protection is included in the guide. New schemes that have been applied are added to the guide.

In this revision, several areas are improved. Among the most notable are the following:

- Insertion of definition in Clause 3 and addition of Glossary in Annex C.
- Revised subclause (7.18) on Scheme 18 for including presently available optional schemes.
- New subclause (7.20) on Scheme 20 for accidental solid neutral grounding.
- New subclause (7.21) on Scheme 21 for alternative scheme for increasing the sensitivity of ground current.
- New subclause (7.22) on Scheme 22 for hybrid ground protection (switching low- and high-resistance schemes) for initial ground fault detection with higher sensitivity to an external fault of the generator and switching to a high-resistance scheme for a generator ground fault.
- New clause (Clause 8) on miscellaneous schemes for ground overcurrent relay locations and the associated benefits.
- Revised clause (Clause 9) on protective device function numbers for all device numbers.
- Revised subclause (A.3.5) on third harmonic detection schemes for example third harmonic measurements.
- Incorporate corrections to Equations (A.1), (A.2), (A.3), and (A.4) as required by IEEE Std C37.101-2006/Cor1:2007.

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IEEE Guide for Generator Ground Protection

1. Overview

1.1 Scope

The guide is intended to assist protection engineers in applying relays and relaying schemes for protection against stator ground faults on various generator grounding schemes. The existing guide is outdated due to rapid technology development. Hence, the revised guide includes new stator ground protection principles that have evolved with the use of new technologies in relay designs. Additional application examples are included, and other issues raised by the users are also addressed. The guide is not intended for the selection of generator or ground connection schemes.

The recommendations made pertain to typical generator installations. However, sufficient background information relating to protection requirements, applications, and setting philosophy is given to enable the reader to evaluate the need to select and apply suitable protection for most situations.

~~Differential relaying will not detect stator ground faults on high-impedance grounded generators. The high impedance normally limits the fault current to levels considerably below the best practical sensitivity of the differential relaying. Separate ground fault protection is then provided.~~

1.2 Purpose

The guide was prepared, in part, to cover new areas due to rapid technology development. The working group has made revision and expansion of the earlier version to include those areas.

In addition, the protective function discussed in this guide may be implemented with a multifunction microprocessor-based protection system (digital system). The protection philosophy, practices, and limits are essentially identical to those of the implementation using discrete component relays. The algorithms used to perform some of the protection functions may be different, but should produce equal or better protection. However, the performance and capability of the digital systems may be superior due to improved frequency response (bandwidth) and thresholds (pickup settings). Other additional features may be available from these systems, like digital fault recording, that enhance the functionality. The improved frequency response and multiple settings groups may be beneficial, especially for start-up protection where older relays needed to be blocked from operation and additional dedicated start-up protective relays are traditionally applied. The start-up relays may not be required with the use of the microprocessor-based protection.

1.3 Description of the guide

Recommended protective schemes and the arrangements to which they may be applied are indicated in Table 1. The use of this table is described in Clause 4 with supporting information provided in subsequent clauses.

Annex A [\(informative\)](#) provides examples of ground overcurrent and overvoltage relay settings for the various protective schemes and the setting coordination with voltage transformer (VT) secondary fuses.

Annex B [\(informative\)](#) provides an example of a procedure used to determine the percent coverage of a high-impedance differential relay.

[Annex C \(informative\) is a glossary \(definitions\) of terms related to grounding protection.](#)

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

[Annex D \(informative\) is a bibliography of available literature concerning the generator ground fault protection from which source material was drawn.](#)

[The methods employed for grounding and fusing the secondary circuits of VTs and the methods for grounding \(CT\) 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 in Table 1 and various schemes. However, all current and VT secondary circuits shall be grounded in a way that is consistent with accepted practices for personnel safety.](#)

[The quantitative units of voltages and currents are expressed in root mean square \(rms\) values in this guide.](#)

[2. Normative references](#)

[The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document \(including any amendments or corrigenda\) applies.](#)

~~This standard shall be used in conjunction with the following publication. When the following standards are superseded by an approved revision, the revision shall apply.~~

IEEE Std C37.2-~~1991~~TM, IEEE Standard Electrical Power System Device Function Numbers [and Contact Designations](#).^{1, 2}

IEEE Std C37.102TM ~~1987~~, IEEE Guide for AC Generator Protection.

IEEE Std C62.92.2TM ~~1989~~, IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems, Part II—Grounding of Synchronous Generator Systems. ~~(ANSI).~~

[3. Definitions, acronyms, and abbreviations](#)

[3.1 Definitions](#)

[For the purposes of this guide, the following terms and definitions apply. The Glossary in Annex C and *The Authoritative Dictionary of IEEE Standards Terms* \[B46\]³ should be referenced for terms not defined in this subclause.](#)

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3.1.1 hybrid ground protection scheme: A combination of low-resistance and high-resistance schemes. This scheme has initially a high sensitivity to detect ground faults with a low-resistance scheme and is switched over to a high-resistance grounding scheme after an internal generator ground fault is detected and the generator breaker is opened (Scheme 22).

3.1.2 phantom tertiary winding: This is a tertiary winding of autotransformer, however, the tertiary winding leads are not brought out of the transformer tank. This is for the purpose of third harmonic suppression, and the rating is usually 10% of the full transformer rating (Scheme 12).

3.2 Acronyms and abbreviations

IOC/IOV relays instantaneous overcurrent/instantaneous overvoltage relays

TOC/TOV relays time overcurrent/time overvoltage relays

GFN ground fault neutralizer

GSU transformer generator step-up transformer

CT current transformer

VT voltage transformer

4. 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 that 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~~seven columns (A–G), 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 Clause 5 of this guide. Vertically, along the left side of the table, heading the ~~eight~~nine rows (I– IX), are one-line diagrams of approved grounding methods for electric generators covered in IEEE Std C62.92. ²⁴ as explained in ~~clause 5. These diagrams will be explained and discussed subsequently. The individual boxes in table 1 list by scheme number (1, 2,~~Clause 6.

Scheme numbers (1, 2, 3, etc.) listed in Table 1 (in the individual boxes) are different applicable ground fault protective schemes that apply for a given ~~generator connection~~(columns in the table) and a given grounding method (rows in the table). For example, the box under column E and row III indicates that protective Schemes 10, 11, 14, 15, 16, 19, and 20 may be applied for single-phase-to-ground fault protection of a wye-connected generator. The neutral is grounded through a ~~low~~high resistance, and the main leads are connected directly to a grounded system through a circuit breaker.

Those boxes that ~~are crossed out and~~ contain no protection scheme numbers (and are marked with a long dash) 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 resonant grounding method, in the neutral of a wye-connected generator directly connected to a grounded system, is a misapplication.

⁴Information on references can be found in Clause 2.

The protective scheme numbers in the boxes refer to protective schemes that are ~~completely illustrated and~~ described in Clause 7 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 start-up and shutdown. Protective scheme numbers without the suffix S represent schemes that are ~~indexed~~expected 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 start-up or shutdown procedures while field excitation is applied, but with the main circuit breaker open. In the box D-VI~~H~~, 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, start-up 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 start-up cycle or is removed late in the shutdown cycle. This start-up 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.

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The protective scheme numbers in Table 1 are arranged in the boxes with the running protective schemes listed first, and the start-up protective schemes, where they apply, listed ~~last~~later. Within each box, the schemes within the brackets are the most widely used. The remainders 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~~VTs on the generator leads may reduce the overall reliability of the generator. 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 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 speed. Under these conditions, the need for start-up or shutdown protection is minimized.

Clause 6 describes grounding methods I through IX. The different grounding methods are shown in the column along the left hand side of the row in Table 1. The diagrams in the column are intended to indicate the different grounding methods and the means for interfacing with the protective relay schemes. The diagram in row I has both a neutral point N and a ground point in the primary circuit, as do those in rows II through 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 of the grounding methods I through 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. Row VIII indicates an ungrounded machine that is grounded only through the system to which it may be connected. Finally, row IX indicates a hybrid ground machine that is grounded as a combination of high resistance and low resistance. Initially, the low-resistance grounding scheme provides great sensitivity for detecting a ground fault in the area of a feeder(s), and the generator bus, then, switches over to the high- resistance grounding scheme to greatly limit the ground current for the generator stator windings during internal ground faults.

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~~ and a secondary resistor. In series with the secondary of the distribution transformer is a ~~current transformer~~ CT primary winding. The secondary winding of this CT 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, the resistor is connected across terminals designated X and Y. 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 CT 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 through 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 CT is indicated with secondary connections to terminals W and Z.

The diagrams for each of the protective schemes in Clause 7 indicate ~~to which terminal~~ the specific interface 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. Similar comments apply to the other protective schemes and the interfacing terminal designations.

Many of the protective functions discussed in this guide may be implemented with a multifunction microprocessor-based protection system (digital system). The protection philosophy, practices, and limits are similar to those of discrete component relays.

GENERATOR CONNECTIONS OVERLAPPED METERS	(A)	(B)	(C)	(D)	(E)	(F)	(G)
I	[1, 7, 10, 18] 2, 3, 4, 9, 11, 20, 5S, 8S	—	—	—	[12, 15] 13, 19 5S, 8S, 21	[1, 7, 10, 18] 2, 3, 4, 9, 11, 20, 5S, 8S	10, 11, 14, 16, 19, 20
II	[1, 7, 10, 18] 2, 3, 4, 9, 11, 50, 5S, 8S, 21	—	—	—	[12, 15] 13, 19 5S, 8S, 21	[1, 7, 10, 18] 2, 3, 4, 9, 11, 20, 21, 5S, 8S	—
III	—	10, 11, 15, 16, 20	—	—	[14, 16] 10, 11, 15, 19, 20	—	10, 11, 14, 16, 19, 20
IV	—	10, 11, 15, 16, 20	—	—	10, 15 16, 19	—	—
V	[6]	—	—	—	—	6, 10, 11, 5S, 20	—
VI		—	[1, 9, 10] 2, 3, 4, 11	[12, 17] 13, 5S	—	—	—
VII		—	—	12, 13	12, 13	—	—
VIII	UNBALANCED	[12, 15], 13, 8S	—	[12, 15], 13, 8S	[12, 15], 13, 8S	—	—
IX	HYBRID	—	—	—	—	—	22

() MARKET WIDELY USED SCHEMES. S - SETTABLE DURING STARTUP OR SHUTDOWN

Table 1—Summary of recommended protective schemes

5. Generator connections

The ~~six~~ [seven](#) different classes of generator connections illustrated in Table 1 are intended to be representative of connections commonly used today. ~~While the connections of the two diagrams in column A are different, the arrangements~~[Arrangements](#) are such that the same protective schemes may be applied to ~~both~~[more than one generator connection](#). The criteria here is that a single-phase-to-ground fault in a generator will neither 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.

[Table 2 shows the comparison of neutral ground methods and summary of the third harmonic current generation levels for Scheme 18 \(see Powell \[B35\]\).](#)

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 step-up transformer may be 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 [and potentially destructive](#) fault current could flow for a ground fault in the stator when the generator is running with field excitation applied. [Furthermore, there may be neutral stability concerns if there is no physical tertiary winding in the autotransformer. For these reasons, the use of an autotransformer to interconnect a generator to its host system should be approached with caution.](#)

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 type of common grounding equipment is employed regardless of the number of generator units that are connected to a given transformer winding.

GENERATOR CONNECTIONS	(A)	(B)	(C)	(D)	(E)	(F)
GROUNDING METHODS	1	2	3	4	5	6
GENERATOR LEADS	7	8	9	10	11	12
GENERATOR LEADS	13	14	15	16	17	18
GENERATOR LEADS	19	20	21	22	23	24
UNGROUNDING	25	26	27	28	29	30
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31	32	33	34	35
36	37	38	39	40	41	42
43	44	45	46	47	48	49
50	51	52	53	54	55	56
57	58	59	60	61	62	63
64	65	66	67	68	69	70
71	72	73	74	75	76	77
78	79	80	81	82	83	84
85	86	87	88	89	90	91
92	93	94	95	96	97	98
99	100	101	102	103	104	105
106	107	108	109	110	111	112
113	114	115	116	117	118	119
120	121	122	123	124	125	126
127	128	129	130	131	132	133
134	135	136	137	138	139	140
141	142	143	144	145	146	147
148	149	150	151	152	153	154
155	156	157	158	159	160	161
162	163	164	165	166	167	168
169	170	171	172	173	174	175
176	177	178	179	180	181	182
183	184	185	186	187	188	189
190	191	192	193	194	195	196
197	198	199	200	201	202	203
204	205	206	207	208	209	210
211	212	213	214	215	216	217
218	219	220	221	222	223	224
225	226	227	228	229	230	231
232	233	234	235	236	237	238
239	240	241	242	243	244	245
246	247	248	249	250	251	252
253	254	255	256	257	258	259
260	261	262	263	264	265	266
267	268	269	270	271	272	273
274	275	276	277	278	279	280
281	282	283	284	285	286	287
288	289	290	291	292	293	294
295	296	297	298	299	300	301
302	303	304	305	306	307	308
309	310	311	312	313	314	315
316	317	318	319	320	321	322
323	324	325	326	327	328	329
330	331	332	333	334	335	336
337	338	339	340	341	342	343
344	345	346	347	348	349	350
351	352	353	354	355	356	357
358	359	360	361	362	363	364
365	366	367	368	369	370	371
372	373	374	375	376	377	378
379	380	381	382	383	384	385
386	387	388	389	390	391	392
393	394	395	396	397	398	399
400	401	402	403	404	405	406
407	408	409	410	411	412	413
414	415	416	417	418	419	420
421	422	423	424	425	426	427
428	429	430	431	432	433	434
435	436	437	438	439	440	441
442	443	444	445	446	447	448
449	450	451	452	453	454	455
456	457	458	459	460	461	462
463	464	465	466	467	468	469
470	471	472	473	474	475	476
477	478	479	480	481	482	483
484	485	486	487	488	489	490
491	492	493	494	495	496	497
498	499	500	501	502	503	504
505	506	507	508	509	510	511
512	513	514	515	516	517	518
519	520	521	522	523	524	525
526	527	528	529	530	531	532
533	534	535	536	537	538	539
540	541	542	543	544	545	546
547	548	549	550	551	552	553
554	555	556	557	558	559	560
561	562	563	564	565	566	567
568	569	570	571	572	573	574
575	576	577	578	579	580	581
582	583	584	585	586	587	588
589	590	591	592	593	594	595
596	597	598	599	600	601	602
603	604	605	606	607	608	609
610	611	612	613	614	615	616
617	618	619	620	621	622	623
624	625	626	627	628	629	630
631	632	633	634	635	636	637
638	639	640	641	642	643	644
645	646	647	648	649	650	651
652	653	654	655	656	657	658
659	660	661	662	663	664	665
666	667	668	669	670	671	672
673	674	675	676	677	678	679
680	681	682	683	684	685	686
687	688	689	690	691	692	693
694	695	696	697	698	699	700
701	702	703	704	705	706	707
708	709	710	711	712	713	714
715	716	717	718	719	720	721
722	723	724	725	726	727	728
729	730	731	732	733	734	735
736	737	738	739	740	741	742
743	744	745	746	747	748	749
750	751	752	753	754	755	756
757	758	759	760	761	762	763
764	765	766	767	768	769	770
771	772	773	774	775	776	777
778	779	780	781	782	783	784
785	786	787	788	789	790	791
792	793	794	795	796	797	798
799	800	801	802	803	804	805
806	807	808	809	810	811	812
813	814	815	816	817	818	819
820	821	822	823	824	825	826
827	828	829	830	831	832	833
834	835	836	837	838	839	840
841	842	843	844	845	846	847
848	849	850	851	852	853	854
855	856	857	858	859	860	861
862	863	864	865	866	867	868
869	870	871	872	873	874	875
876	877	878	879	880	881	882
883	884	885	886	887	888	889
890	891	892	893	894	895	896
897	898	899	900	901	902	903
904	905	906	907	908	909	910
911	912	913	914	915	916	917
918	919	920	921	922	923	924
925	926	927	928	929	930	931
932	933	934	935	936	937	938
939	940	941	942	943	944	945
946	947	948	949	950	951	952
953	954	955	956	957	958	959
960	961	962	963	964	965	966
967	968	969	970	971	972	973
974	975	976	977	978	979	980
981	982	983	984	985	986	987
988	989	990	991	992	993	994
995	996	997	998	999	1000	1001

Table 1—Generator connections, generator grounding methods, and protective scheme numbers

The circuit arrangements of connection D and E indicate generators connected directly to the system bus without any interposing step-up transformers. In general, these may be relatively small generators, and they will be connected to a solid or low impedance grounded 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.

Table 2—Comparison of neutral ground methods

<u>Type of neutral grounding</u>	<u>Fault current characteristics of grounding method</u>	<u>Magnitude of expected third harmonics current</u>	<u>Comments</u>
<u>Ungrounded generator</u>	<u>0 A</u>	<u>None</u>	<u>0 A for the first ground fault, but the second ground fault will develop similar fault current level with solidly grounded method.</u>
<u>Solidly grounded generator</u>	<u>$I_{\Phi G} \geq I_{3\Phi}$</u>	<u>Appreciable</u>	<u>A phase-to-ground fault current level ($I_{\Phi G}$) may be significantly greater than three-phase fault current level ($I_{3\Phi}$).</u>
<u>Low-resistance grounded generator</u>	<u>400 A $\sim$ 1200 A</u>	<u>Appreciable</u>	<u>Appreciably reduced ground fault current by a reactance.</u>
<u>Medium-resistance grounded generator</u>	<u>200 A $\sim$ 400 A</u>	<u>Appreciable</u>	<u>A variation of low-resistance grounding method will further reduce the ground fault current level.</u>
<u>High-resistance grounded generator</u>	<u>10 A $\sim$ 25 A</u>	<u>Negligible, small</u>	<u>A phase-to-ground fault current is fed by all capacitors on the generator and generator bus.</u>
<u>Low-reactance grounded generator</u>	<u>$I_{3\Phi} \geq I_{\Phi G}$</u>	<u>Appreciable</u>	<u>A phase-to-ground fault current level ($I_{\Phi G}$) is nearly equal or less than a three-phase fault current level ($I_{3\Phi}$).</u>
<u>Hybrid grounded generator</u>	<u>10 A $\sim$ 25 A (high resistance) and 200 A $\sim$ 400 A (low resistance)</u>	<u>Appreciable</u>	<u>The first ground fault current level will be 200 A $\sim$ 400 A with low-resistance grounding, and 10 A $\sim$ 25 A after switched to a high-resistance grounding scheme.</u>

Connection G depicts the situation, often found in industrial applications, where a generator is directly connected to a common bus. Local facility loads are also connected to this bus. When the generator is not connected, the local loads are powered from the power transformer and the ground source is supplied by the grounded wye of the transformer. When the generator is connected, there are two sources of ground fault current, the generator and the transformer. In many cases both ground sources have ground resistors in the neutral to limit the magnitude of the ground fault current. If the transformer source is disconnected, the

[generator can supply power to some or all of the local facility loads. In this case the generator provides the ground source for the local facility electrical system. In some cases the generator voltages are much higher \(e.g 22 kV, 27 kV\) than the suitable local loads' voltage. In this case the unit auxiliary transformer\(s\) is usually connected to the generator bus to feed the local loads. Coordination of the generator ground protection with the auxiliary load ground protection can be disregarded as long as the auxiliary transformer connection, usually a delta-wye-grounded connection, does not provide a path for circulation of the generator ground current for ground fault on the auxiliary bus side of the auxiliary transformer.](#)

[A variation of connection G may be found in instances in which overhead distribution circuits are served directly from a generator bus. Often, these applications involved either hydroelectric or gas-turbine generators installations. It is the fact that overhead circuits originate at these buses that leads to the desire that the system neutral be effectively grounded. Since generators cannot normally be solidly grounded \(due to the large magnitude ground fault current\), these applications often involve low-reactance grounding of the generator neutral.](#)

[A critical requirement is that the relaying system provides selective ground fault detection for any of these operating permutations.](#)

[5.1 Example use of Table 1](#)

[Table 1 is a list of possible combinations of grounding methods and possible types of relay schemes.](#)

[NOTE—The figures in Table 1 are shown only for reference. Details of the respective figures and schemes can be found in Clause 7.⁵](#)

[If the generator \(Y stator windings\) connected to the delta windings of the generator step-up \(GSU\) transformer, the grounding methods I, II, or V from Table 1 can be used.](#)

[If the selected grounding method is I, then the most widely used relay schemes are Scheme 1 \(overvoltage relay\), Scheme 7 \(overvoltage relay\), Scheme 10 \(overcurrent relay\), and Scheme 18 \(100% ground fault detection relay\).](#)

[In addition, it is possible to apply one of Schemes 2, 3, 4, 6, 9, 11, 20, 5S, or 8S.](#)

[6. Generator grounding methods](#)

This guide describes protection for five of the six [generator grounding categories methods](#) described in IEEE Std C62.92.2. The six methods are as follows:

- 1) Effectively grounded
- 2) Low ~~inductance~~ [reactance](#) grounded
- 3) Low resistance grounded
- 4) Resonant grounded
- 5) High resistance grounded
- 6) Ungrounded

[NOTE—The selection of these generator grounding methods is beyond the scope of this guide. For the advantages/disadvantages of these six generator grounding methods, refer to IEEE Std C62.92.2.](#)

An effectively grounded system is a form of low inductance grounded system and is not considered in this guide. The guide considers distribution transformer and high resistance grounding as a single category. This

guide lists them as separate grounding methods since each requires a different type of protective scheme. The protection for two additional methods of grounding, high [resistance](#) and medium resistance grounding transformer grounded, is explained in this guide. The following ~~nine~~^{eight} grounding methods ([including ungrounded systems](#)) considered in this guide are as follows:

- a) High resistance grounded (distribution transformer grounded) [generator](#)
- b) High resistance grounded (neutral resistor grounded) [generator](#)
- c) Low resistance grounded (neutral resistor grounded) generator
- d) Low reactance grounded (neutral reactor grounded) generator
- e) Resonant grounded (GFN grounded) generator
- f) High resistance grounded (grounding transformer grounded) generator
- g) Medium resistance grounded (grounding transformer grounded) generator
- h) Ungrounded generator

5.1 Method I: High resistance grounded (distribution transformer grounded)

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 volt amperes in the zero sequence capacitive reactance 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 to 25 primary amperes. This is not of sufficient magnitude to operate standard generator differential relays. In general, the W-Z current

⁵Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

NOTE—The designation of W, Z, R, S, etc., in the following grounding methods refer to Table 1.

6.1 Method I—Effective high resistance ground with a distribution transformer

This grounding method utilizes a distribution transformer that provides high resistance in the primary circuit with a small resistance in the secondary of the distribution transformer. The primary of the distribution transformer is connected between the generator neutral and ground. The ground resistance value (R) is generally extremely small ($< 1 \Omega$); however, the imposed ohmic value to the primary circuit becomes extremely high resistance value (in the order of kilohm. See A.1.1). The high resistance is $N^2 R$ where N is the turn ratio and R is the ohmic value of a resistor in the secondary. The grounding equipment should be rated in accordance with IEEE Std C62.92.2 or Annex A of this guide. 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 A to 25 A primary amperes. current, which is not of sufficient magnitude to operate standard generator differential relays. In general, the W-Z CT will have a ratio of unity, and the R-S CT ratio is usually selected so that its secondary current will be approximately equal to the primary current in the generator neutral.

A generator system grounded through a distribution transformer with a secondary resistor has certain characteristics that may have the following desirable features:

- Mechanical stresses and fault damage are limited during phase to ground faults by restricting fault current.
- Transient over voltages are limited to safe levels.
- The grounding device is more economical than direct insertion of a neutral resistor.

However, a disadvantage of this [high resistance](#) grounding scheme is that surge protective equipment must be selected on the basis of higher temporary overvoltages during ground faults.

NOTE—In general, the voltage rating of electrical equipment is selected on the basis of the grounding reference point. If electrical equipment is installed near the ground point (grounded scheme), the equipment may be selected on based a phase to ground voltage. However, if the equipment is installed far from the ground reference point (non grounded scheme), the equipment may be selected based on the phase to phase voltage. The grounding effect of a high resistance ground scheme is a similar overvoltage phenomenon to a non grounded scheme. The electrical equipment needs to be selected based on the phase to phase voltage.

6.2 Method II—High resistance ground with a neutral ground resistor

This method of grounding is functionally equivalent to the method described in 6.1. In this method, the resistor is sized directly to limit the single phase to ground fault current to the same magnitude as in the method in 6.1 without the use of a distribution transformer. However, ~~the voltage transformer voltage ratings are the~~ [resistor rating is](#) selected on the same basis as those for the distribution transformer in method 6.1 (see Annex A for an example). The W Z CT ratio is generally selected to be unity.

6.3 Method III—Low resistance ground with a neutral ground resistor

~~Method III illustrates a low resistance grounding arrangement.~~ This type of grounding method permits fault current many times higher ([400 A ~ 1200 A primary current](#)) than those ~~produced by~~ methods described in 6.1 and 6.2. In ~~the case of low resistance grounding methods~~ [this method](#), 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. The main advantage of low resistance grounding is the ability of the neutral resistance to limit ground fault current to a moderate value while limiting the transient overvoltages to 2.5 times the phase to ground voltage or less. ~~However,~~ [Surge](#) arresters with maximum continuous overvoltage (MCOV) capability that can tolerate full line to line voltage until the generator is tripped are required.

The current through a neutral resistor can be limited to any value, but usually it ranges from about several hundred amperes to about 1.5 times the normal rated generator current. The lower limit may be based on the sensitivity of the generator ground differential relays. The upper limit of 1.5 times normal rated current is related to the loss in the resistor during single phase to ground faults. A value of 1.5 times normal current through a neutral resistor gives a power loss of 50% of the [power](#) rating (kVA) of the generator. The main disadvantages of low resistance grounding is the cost of the grounding resistor and the possibility of iron lamination burning from the higher ground fault current.

6.4 Method IV—Low ~~inductance~~ reactance ground with a neutral ground reactor

~~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 described in 6.1 and 6.2. In the case of low inductive reactance grounding methods, the single phase to ground fault current is high enough to operate some generator differential relays for faults in the stator, except for those near the neutral end of the machine. [In general, the reactance value of low reactance grounding method is selected to suppress a phase to ground fault current into approximately three phase fault current level.](#)

[NEMA standards do not require that standard generators have the mechanical bracing required to sustain operation with their neutrals solidly grounded. Low reactance grounding is often selected in applications where system planning considerations call for effective grounding \(as defined in Annex C\) of the system neutral. Note that effective grounding of generators through the use of low reactance neutral grounding reactors requires special consideration of both ground fault magnitudes, and potentially also of third harmonic current circulation.](#)

6.5 Method V—Resonant ground with a ground fault neutralizer~~(GFN)~~

This grounding method illustrates the ground fault neutralizer (GFN) arrangement. In this grounding method, a distribution type transformer with a ratio selected, as in method 6.1, 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 one third 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 capacitive reactance of the circuit does not change significantly for different system conditions. This method may not be readily applied to units arranged as in column F of Table 1, ~~such as~~ when low side breakers are applied. [In general, the resonant grounding method suppresses a phase to ground fault current in less than 1 A primary current.](#)

[In the grounding methods described in 6.1 through 6.5, the neutral CT is shown to be connected between the fault limiting device and ground. This CT could be located on either side of the fault limiting device depending on the preference of the user. The insulation level of the CT should be compatible with the possible voltage to which it may be exposed.](#)

6.6 Method VI—High resistance ground with a delta grounded wye transformer

This grounding method uses three distribution transformers whose primary windings are connected to the generator leads in a wye configuration, while the secondary are connected in broken delta configuration with a resistor. ~~These transformers must have their primary voltage rating equal to the line to line voltage of the generator. Secondary voltage is commonly 120 V or 240 V. As in the case of 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 three phase zero sequence reactive volt amperes in the zero sequence capacitance of the generator windings, its leads, and the windings of the transformers connected to the generator terminals. The total capacity of the three transformers must be 1.732 times the watt dissipation of the resistor, and the voltage applied to the resistor is 1.732 times the transformer rated secondary voltage. The grounding equipment should be rated according to IEEE Std C62.92.2.~~ This grounding method used on ungrounded systems such as those having delta connected generators and power transformers. [In general, a high resistance grounding method will suppress the phase to ground fault current in a range of 10 A to 25 A primary current.](#)

6.7 Method VII—Medium resistance ground with a delta grounded wye transformer

This grounding method uses either a zig zag transformer or a wye delta 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. [The medium resistance grounding method is a variation of low resistance grounding \(400 A to 1200 A primary current\) and provides a phase to ground fault current in a range of 200 A to 400 A primary current.](#)

6.8 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 listed in row VIII of Table 1.

The advantages of this class are essentially the same as for high resistance grounding except that the maximum fault current is somewhat less [through the leakage capacitances](#). A disadvantage is that excessive transient overvoltages may result from switching operations or intermittent faults.

~~In grounding methods I through 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.~~

6.9 Method IX—Hybrid ground (switching low resistance to high resistance)

[If the power system is designed to operate either with both sources in parallel or with either source being independent, then the hybrid system shown in Scheme 22 provides a good alternative. The generator has both low and high resistance grounding schemes. Under normal operating conditions, the generator has medium ground fault current \(200 A to 400 A primary current\) that is governed by the medium resistance grounding scheme. This helps ground fault detection on a local feeder by an instantaneous overcurrent relay and eliminates unnecessary shutdown of the generator as well as other local loads. If a ground fault is detected in the generator zone, the protection trips the low resistance ground source. Simultaneously, the medium resistance grounding scheme is switched to a high resistance scheme to limit the fault current \(10 A to 25 A primary current\) and the core burning associated with it, also preventing any transient overvoltage condition from occurring. Refer to Figure 22 and Clause 7 for further explanation of Scheme 22.](#)

7. Protective schemes

The protective schemes listed (by number) in Table 1 are described in this clause along with their suitability for the grounding methods discussed in Clause 6. The electrical characteristics of the relays represented by the device function numbers in the figures illustrating each scheme are defined in Clause 9.

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 circuits of VTs connected to the generator leads. If the wye-connected secondary circuit of these VTs 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 VT secondary fuses. However, coordination with the primary fuses is still required.

~~³The numbers in brackets correspond to those of the bibliography sources in annex C.~~

For ~~ground fault neutralizer~~ GFN grounding, the primary neutral connections of the two sets of wye-wyeconnected generator VTs are tied together and to the generator neutral using an insulated conductor. The secondary neutrals are grounded at the VT cubicle. Grounding of the primary neutral connections at the cubicle is not used since the resulting phase-to-ground inductive reactance comprising the magnetizing branch of the VTs would detune the resonant circuit consisting of the generator system capacitance to ground and the neutral reactor.

A complete discussion of VT fusing is given in the IEEE Committee Report [B43] and A.4.

Usually, a generator is ~~cleared~~[isolated](#) 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.