

More About Standby Generator Grounding, GFP, and Currents that Go Bump in the Night

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Abstract—The issue of generator grounding, separately derived systems, and the application of three-pole and four-pole transfer switches continues to be misunderstood and misapplied by design engineers, in spite of several papers on the subject. Incorrect generator grounding and/or incorrect transfer switch selection can result in noncode-complying installations, intermingling of ground and neutral currents, and possible incorrect ground-fault sensing. In order to properly ground multiple service and multiple generator installations, the electrical design engineer must have an in-depth understanding of all of the variables involved.

Index Terms—Generator grounding, ground-fault protection, separately derived system, stray neutral and ground currents, three-pole and four-pole automatic transfer switches.

I. INTRODUCTION

IN 1978, West presented a paper [2] which addressed grounding requirements for generators and other separately derived systems, the application of three-pole and four-pole automatic transfer switches (ATS's), and the effect of grounding and transfer switch selection on ground-fault protection (GFP) performance. In 1988, this author published a paper [1] which explained in depth the GFP problem created by incorrectly grounded standby generators and incorrect ATS selection. In spite of at least two papers on the subject, generator grounding, separately derived systems, and the application of three-pole and four-pole transfer switches continue to be misunderstood by electrical design engineers. This has resulted in many installed systems that are not code-complying. Some of these systems result from the undesirable intermingling of ground and neutral currents, which can cause unwanted potential differences, voltages capable of driving common mode currents, and incorrect ground-fault sensing. Other installations, whether code-complying or noncode-complying, may show little or no deleterious effect, because of favorable system impedances which tend to attenuate "stray" currents.

The purpose of this paper is to look at a variety of systems utilizing multiple services, multiple generators, and multiple transfer switches, and to analyze ground and neutral currents in terms of their effect on system safety and reliability. This paper will examine configurations that are known to violate the National Electrical Code (NEC), and it will examine possible problems with systems known to comply with the NEC. The

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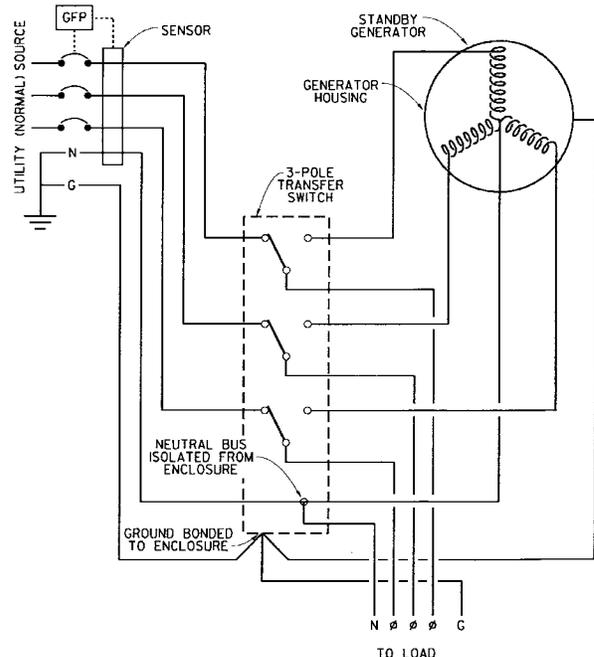


Fig. 1. Code-complying system with neutral ungrounded at the generator.

paper will address new systems, as well as existing systems, that are candidates for possible retrofit.

II. THE CLASSIC PROBLEM

In order to better understand the classic generator grounding/transfer switch selection problem, three single-generator/single-service scenarios will be examined. Fig. 1 shows a system with one 480Y/277-V service, one 480Y/277-V standby generator, and one three-pole transfer switch. According to the 1993 NEC, the system in Fig. 1 is code-complying because: 1) this "premises wiring system" is a single "separately derived system" with a "solidly connected grounded circuit conductor" (the neutral) between the service and the generator [250-5(d)]; 2) the "separately derived system" has its neutral conductor insulated and grounded at a single point (250-152); and 3) the bonding jumper is located between the source and the "first disconnecting means or overcurrent device" [250-26(a)]. Not only does the system comply with the NEC, but there are no problems with ground-fault sensing. All ground currents will return to the service switchboard outside of the ground-fault sensor, and all neutral currents will return to the source through (or inside) the sensor.

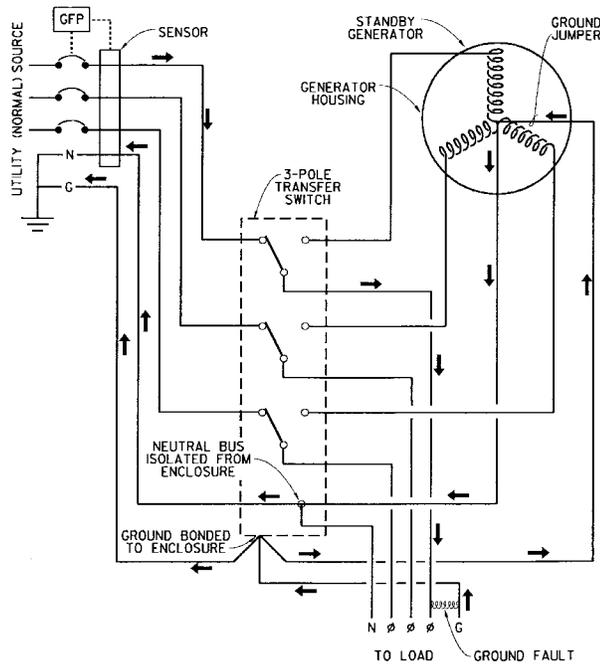


Fig. 2. Neutral current resulting from ground fault.

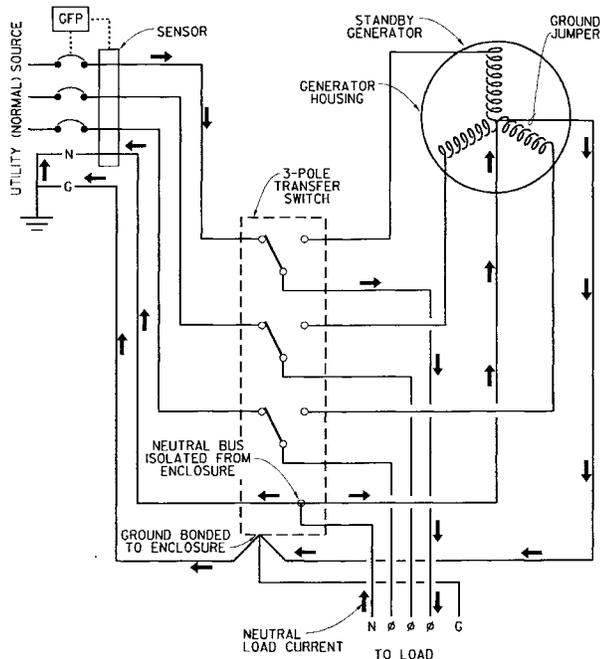


Fig. 3. Neutral current returning via ground.

Fig. 2 shows a system with a single 480Y/277-V service, a single 480Y/277-V generator, and a single three-pole transfer switch. The only difference between Fig. 1 and Fig. 2 is that Fig. 2 has the generator neutral grounded at the generator. We will assume, for the sake of argument, that the electrical design engineer chose to ground the neutral at the generator because the generator is a great distance from the building service entrance, and the engineer is concerned about the generator neutral "floating" relative to ground as a function of unbalanced load current. A ground fault is shown on the

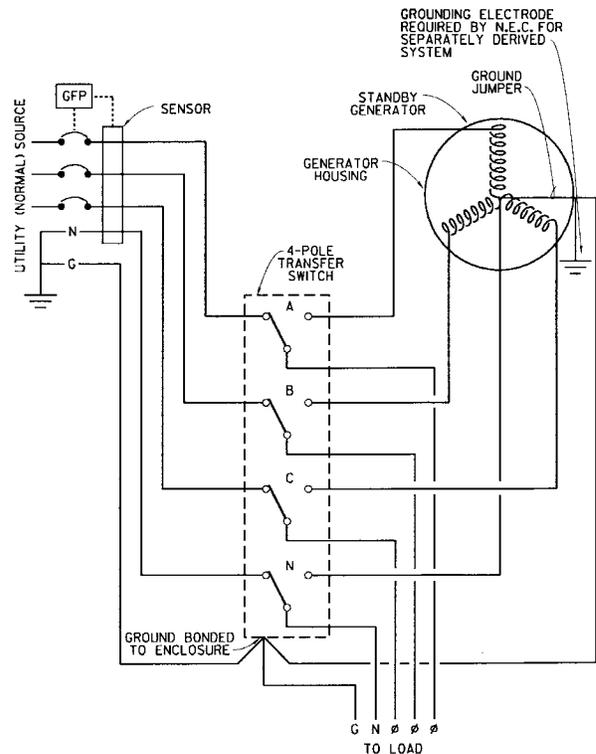


Fig. 4. Grounded generator neutral with four-pole transfer switch.

load side of the transfer switch, returning to the source via the main switchboard outside of the GFP sensor. Fig. 2 also shows a portion of the ground-fault current returning to the source by way of the emergency generator, with a portion of the current returning via the neutral through the GFP sensor. The "apparent" ground fault sensed by the GFP relay is less than the actual ground-fault current.

Therefore, ground-fault sensing is inaccurate and can possibly result in failure of the GFP relay to operate as desired.

The system in Fig. 3 is identical to the system in Fig. 2. The neutral has a load current that returns to the source via the main switchboard, passing through the GFP sensor. However, a portion of the neutral current returns via the standby generator and ground, passing outside of the GFP sensor. In this case, the "apparent" ground-fault current is greater than the actual ground-fault current, which is zero. This can possibly result in nuisance tripping by the GFP relay.

Fig. 4 shows the same system shown in Fig. 2 and 3, except that a four-pole transfer switch is used instead of a three-pole switch. The open neutral at the transfer switch prevents "mixing" of ground and neutral currents. In this case, all ground currents return to the source outside of the GFP sensor, and all neutral currents return to the source inside of the sensor. This arrangement is code-complying, representing two "separately derived systems," each with its neutral grounded.

III. WAYWARD NEUTRAL CURRENTS

Fig. 5 shows a single 480Y/277-V service, a single 480Y/277-V standby generator, and three three-pole transfer switches. Since the scheme in Fig. 5 represents a single "separately derived system," and it is grounded at a single

TABLE I
STRANDED COPPER WIRE IMPEDANCE IN STEEL CONDUIT

AWG Size	DC Res. Ohms/1000'	60 Hz. Res. Ohms/1000'	60 Hz. React. Ohms/1000' Note A	60 Hz. Imped. Ohms/1000' Note A	Conduit Size for 1/c Imped.	DC Res of Conduit Ohms/1000'	1/c Imped. in Conduit Note B	1/c Imped. in Conduit Note C	Multiplier Note D
8	0.778	0.811	0.075	0.814	1/2	0.321	1.05	2.10	2.57
6	0.491	0.510	0.069	0.515	3/4	0.242	0.78	1.56	3.03
4	0.308	0.321	0.063	0.327	3/4	0.242	0.78	1.56	4.77
2	0.194	0.202	0.059	0.210	1	0.154	0.56	1.12	5.33
1/0	0.122	0.128	0.054	0.139	1	0.154	0.56	1.12	8.05
2/0	0.097	0.102	0.053	0.115	1	0.154	0.56	1.12	9.74
3/0	0.077	0.081	0.052	0.096	1 1/4	0.120	0.44	0.88	9.18

- NOTE A: Represents X and Z for 3/c in conduit with canceling effect of magnetic flux.
- NOTE B: Represents impedance of conduit and conductor with conductor bonded to conduit at both ends.
- NOTE C: Represents impedance of conductor only with conductor not bonded to conduit.
- NOTE D: Multiplier applied to 3/c value to get 1/c value.

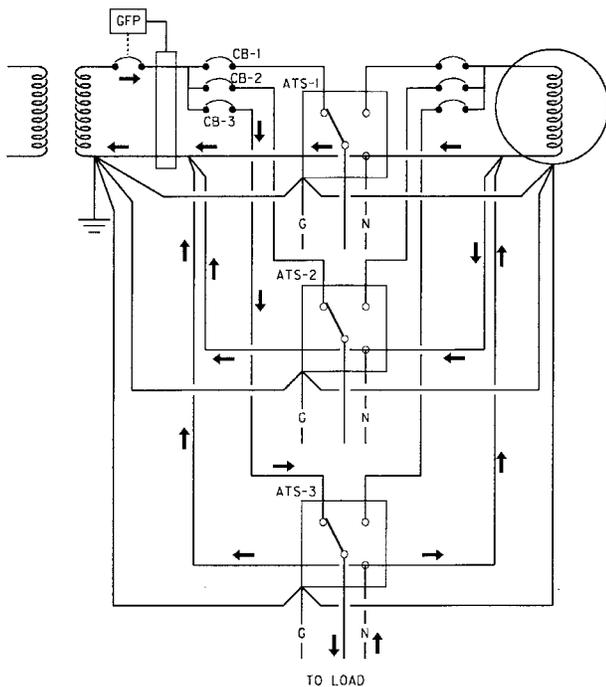


Fig. 5. Neutral currents returning to source via multiple neutral paths.

point, this system complies with the NEC. There is, however, a potential problem with the neutral currents. For example, not all of the ATS-3 neutral current returns to the source through its intended neutral, but returns via multiple “backdoor” neutral paths. There is no problem with operation of the main GFP unit, because all neutral current passes through the main GFP sensor. There may be a problem, however, with operation of a branch GFP unit, depending on the impedances of the neutral circuits and the proportion of the neutral current that returns to the source via the “backdoor” neutral paths. The CB-3 neutral current returning through the GFP sensors for CB-1 and CB-2, for example, appear as ground-fault currents to the GFP sensors in all three circuit breakers.

The system shown in Fig. 5 is typical of systems found in small hospitals with essential electrical systems consisting of three automatic transfer switches. Because the reactance of a single conductor in a metallic conduit is very high and the “backdoor” path generally is longer than the primary (intended) neutral path, the percent of neutral current returning to the source by way of the “backdoor” will be relatively small. The phase relationship of neutral currents flowing back to the source via parallel (unintended) paths will also affect current levels and the degree to which GFP sensing is affected. It is important to note that hospitals with GFP mains are required to have “an additional step of ground-fault protection in the next level of feeder disconnecting means downstream toward the load” [517-17(a)].

Table I has single-conductor (in steel conduit) impedance values taken from the *IAEI Soares Book on Grounding* [3]. For steel conduit, this table shows the relative magnitude of single-conductor impedances compared to the impedances of three single conductors. The three-conductor value assumes a balanced three-phase circuit with the canceling effect of the magnetic flux. Table I demonstrates that the single conductor impedance will be 2.5–9.2 times higher than the three-conductor impedance for copper wire sizes #8–#3/0. At the time of this writing, the *IAEI Soares Book on Grounding* is the only known source providing a table of single-conductor (in steel conduit) impedances. The table in the *IAEI Soares Book* includes only a limited range of wire sizes (#8–#3/0), and the impedance values shown are suspect. With the conductor *not* bonded to the conduit at each end, the single-conductor impedance appears to be a function of conduit size, rather than wire size. In addition to the questionable impedance values in the *IAEI Soares Book*, our use of these values for determining our “backdoor” neutral currents may not be appropriate, because the conduit sizes and wire/conduit geometries in our examples are different from the *IAEI Soares* examples. In spite of these problems, we will use the *IAEI Soares* values that are shown in Table I, and we will assume

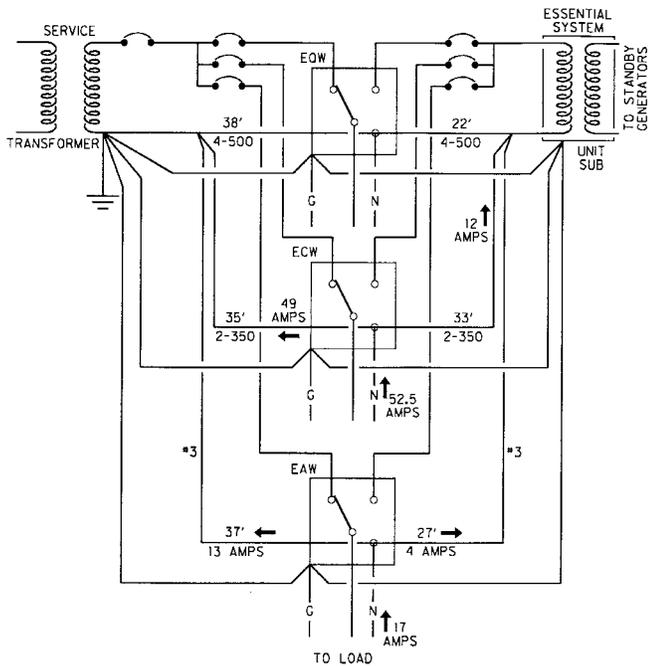


Fig. 6. Measured neutral currents returning to source via multiple neutral paths.

that neutral conductors larger than #3/0 will have single-conductor (in steel conduit) impedance values that are ten times the three-conductor (in steel conduit) values. These assumed values will be used in current-divider equations to determine the amount of current taking the primary (intended) current paths and the amount taking the “backdoor” paths. Its important to note that the only reliable method of determining current division is field measurement.

IV. CASE STUDY #1

Fig. 6 shows a system with a 208Y/120-V service, a 2400-208Y/120-V essential system unit substation (fed by 2400-V standby generators), and three three-pole transfer switches. Since the neutral is common to the service entrance and the essential system substation, this system represents a single “separately derived system” grounded at a single point. The system in Fig. 6 is installed and operating at an existing health care facility. Field measurements indicate that the total ATS “EAW” neutral load is 17 A, with 13 A returning to the source via the primary (intended) neutral, and only 4 A return to the source via the “backdoor” route. ATS “ECW” has a neutral load of 53 A, with 49 A returning to the source via the primary neutral path and 12 A via the “backdoor” route. The discrepancy in total amperes could be due to variations in the current between readings or circulating currents in the loop created by the neutral conductors. Fig. 7 shows a similar system in the same health care facility. ATS “EAE” has a measured neutral load of 21 A. Substantially all of this current appears to return via the primary neutral path.

V. MORE EXAMPLES

The diagram in Fig. 8 shows an installation with a single 480Y/277-V service and two generators (each with a single

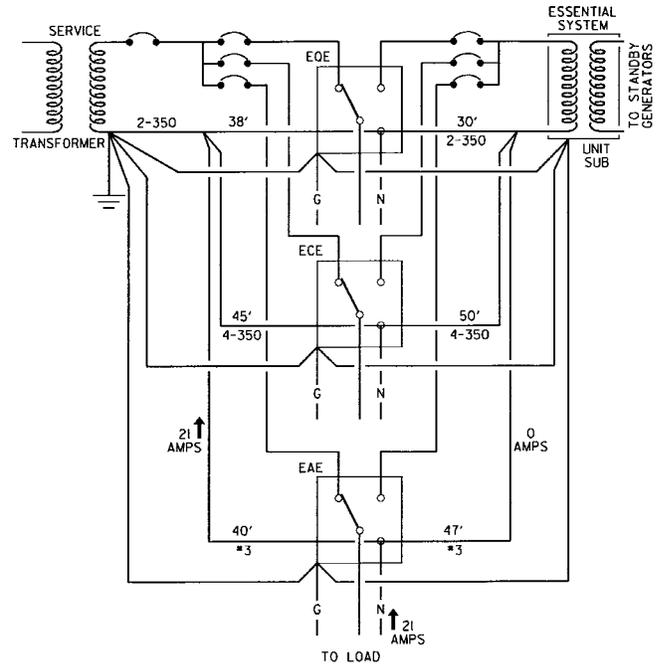


Fig. 7. Measured neutral currents returning to source via multiple neutral paths.

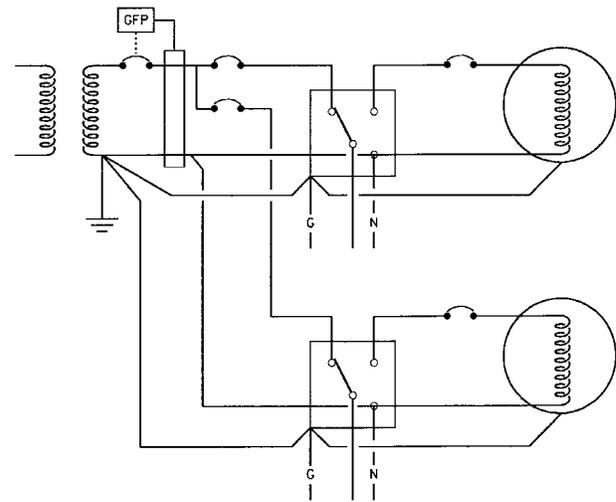


Fig. 8. Single service, multiple generator, single ATS per generator.

three-pole ATS). This system is a single “separately derived system” with the neutral grounded at a single point. It complies with the NEC, and there is no intermingling of ground and neutral currents. Since each generator has a single automatic transfer switch, there is no “backdoor” path for neutral currents.

Fig. 9 is similar to Fig. 8, except each generator in Fig. 9 has two ATS's. Like Fig. 8, the system in Fig. 9 complies with the NEC, and there is no intermingling of ground and neutral currents. Because there are two three-pole transfer switches per generator, a “backdoor” route exists for neutral currents.

The system in Fig. 10 has two 480Y/277-V electrical services, a single 480Y/277-V generator, and two three-pole transfer switches. Since the transfer switches have solid neutrals, this system represents a single “separately derived sys-

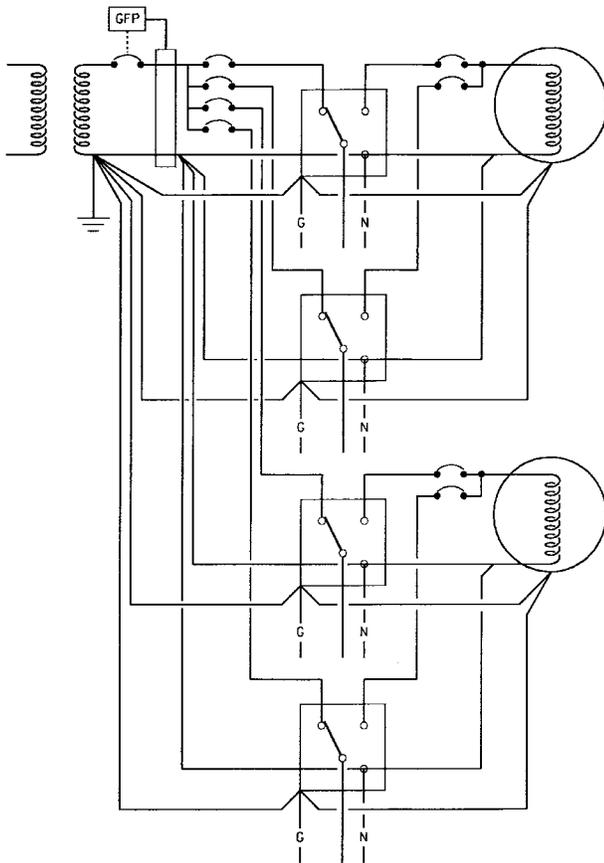


Fig. 9. Single service, multiple generator, multiple ATS's per generator.

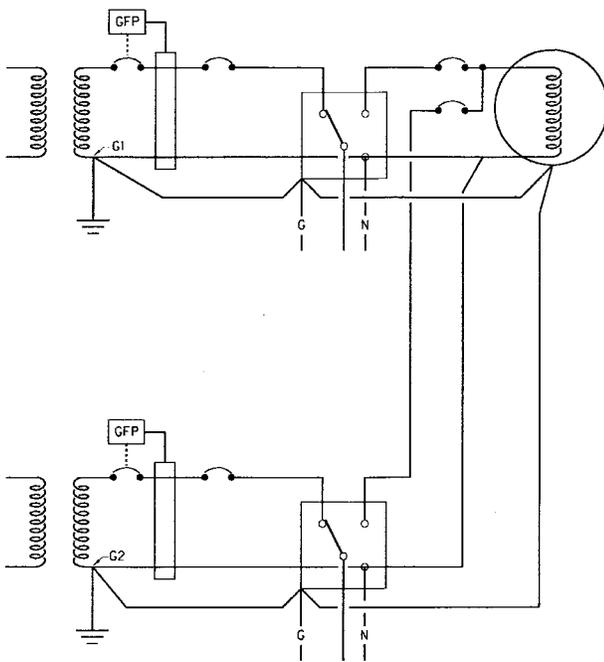


Fig. 10. Multiple service, single generator, single three-pole ATS per service.

tem.” It does not comply with the NEC, because the neutral is grounded at two points. Multiple “backdoor” paths exist for neutral currents via the “second ground” at point G2. Two ground return paths are shown for neutral currents—one via

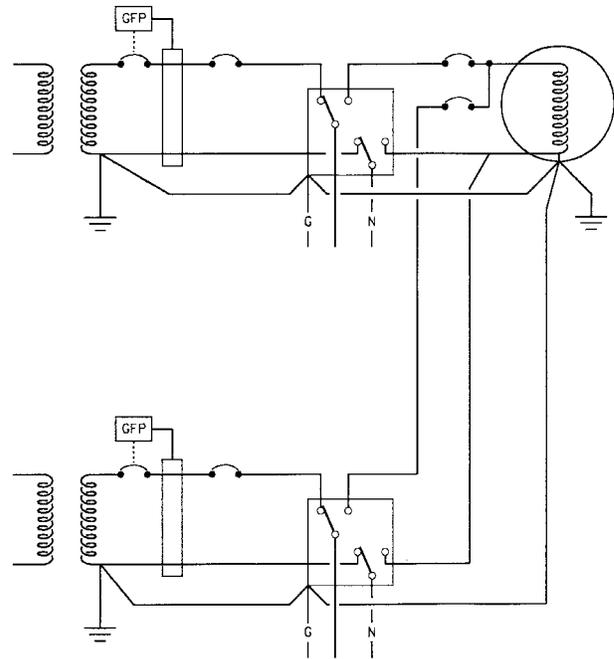


Fig. 11. Multiple service, single generator, single four-pole ATS per service.

earth ground and one via conductor ground. However, these “backdoor” neutral currents should be very small because they must overcome the grounding impedance, as well as the greater length and higher reactance of the “backdoor” paths. It is not impossible for ground-fault currents to return to the source via the neutral conductor, but this scenario is even less plausible than the one just described for neutral currents. For our purposes, it will be assumed that once ground currents reach “ground” they are unlikely to “jump back” on a neutral conductor for the purpose of returning to the source.

The system shown in Fig. 11 is like the system in Fig. 10, except the ATS's are four-pole and the generator is grounded. It represents three “separately derived systems”—each grounded at a single point. This arrangement is code-complying and free from current problems that might adversely effect GFP function.

The system in Fig. 12 is similar to the system in Fig. 10, except that each service has two three-pole transfer switches. Again, this system represents a single “separately derived system” grounded at two points. This system has all of the problems that exist for the system in Fig. 10, plus an additional “backdoor” neutral path created by the additional transfer switches.

Fig. 13 shows the system in Fig. 12 with four-pole transfer switches and a grounded generator. This system, like Fig. 11, represents three separately derived systems, each grounded at a single point.

VI. CASE STUDY #2

Fig. 14 shows an installed and operating hospital electrical system with two 480Y/277-V electrical services, two standby generators operating in parallel on a common synchronizing bus, and 13 ATS's. Because seven of the 13 ATS's have solid neutrals, the entire system represents a single “separately

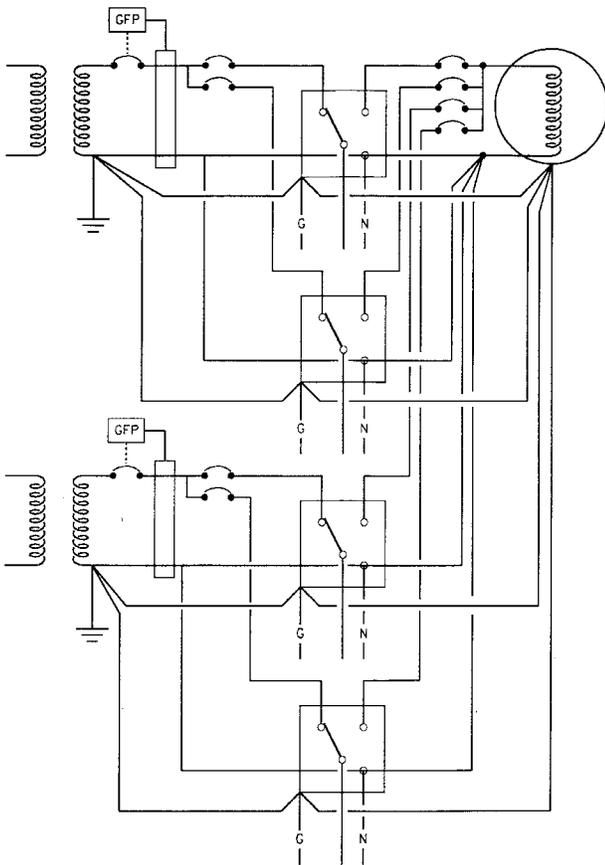


Fig. 12. Multiple service, single generator, multiple three-pole ATS's per service.

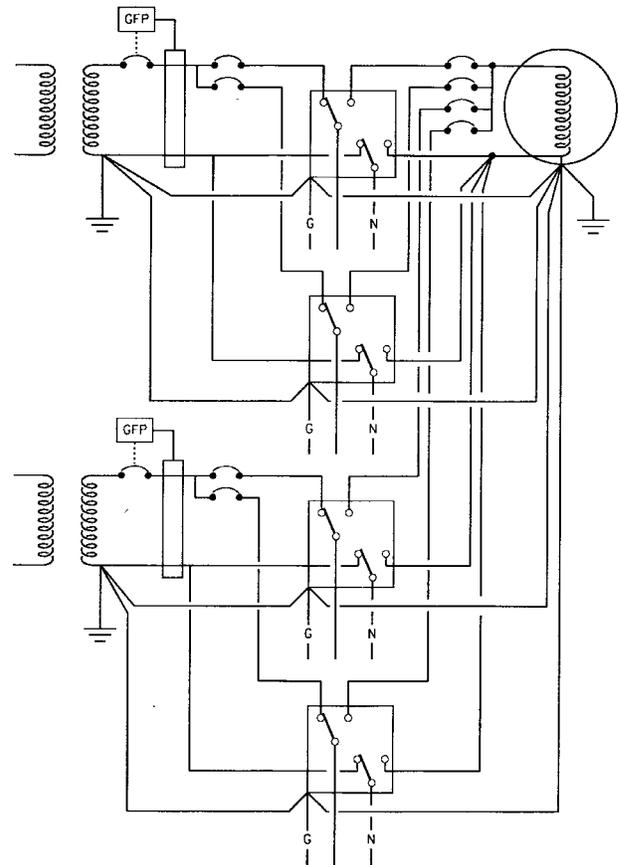


Fig. 13. Multiple service, single generator, multiple four-pole ATS's per service.

derived system." For this reason, the generator neutrals are not grounded at the generators or at the synchronizing switchgear. The system, however, is not code-complying because the neutral is grounded at two points—once at each service. One solution to the problem would require replacing all of the three-pole solid-neutral ATS's with four-pole switches. This solution, however, would be expensive, would disrupt the operation of the hospital, and could possibly place patients at risk. Another solution would be to study possible ground/neutral current problems and determine if "stray" currents pose an unacceptable risk.

First, the problem of "neutral currents returning via ground" will be addressed. In Fig. 14, ATS "PEC" load currents are shown returning to the source by way of the primary (intended) neutral path as well as by "backdoor" routes. Using approximate values of "single-conductor-in-conduit" impedances taken from Table I and ignoring the grounding electrode impedances, it can be determined that approximately 60% of the neutral current returns to the source via the primary (intended) neutral path. The remaining current (40%) is distributed among the multiple "backdoor" paths. Unfortunately, 75% of the "backdoor" current (30% of the total current) passes through ATS "ECF," creating a possible ground-fault problem for the breakers feeding ATS's "PEC" and "ECF." In fact, neutral currents from all transfer switches will tend to return via ATS "ECF." Even though the single conductor impedance is high, the total impedance of this path

will be relatively small, because the conductors are large (2–350 MCM) and the length is short. In this example, we chose to ignore the grounding electrode impedance. Using an impedance of even 1Ω per grounding electrode changes the percentage of current flowing in each neutral path.

Measurements taken at this hospital show neutral currents of between 0 and 3 A on the seven transfer switches, so ground fault should not be problematic with ground-fault units set at several hundred amperes. In fact, neutral currents are so small that our calculations of impedance and the resulting current division could not be verified.

In analyzing ground-fault currents, we find that ground-fault currents cannot "get on" the neutral by way of the standby generators, because the generator neutrals are not grounded at the generators. On the other hand, a ground-fault current at ATS "EC," for example, could conceivably embark on a "backdoor" route to the generator ground bus, then to the MSA ground/neutral bus, and then return to the source (MSB) via the earth ground. However, the percentage of ground-fault current returning this way should be very small.

With the blessing of the authority having jurisdiction, the system in Fig. 14 remains in service. Because neutral currents are very small, and because ground impedances encourage ground-fault currents to return by ground paths (and not neutrals), the hospital saved the great expense of replacing 13 three-pole ATS's with four-pole ATS's and has experienced no ground-fault problems.

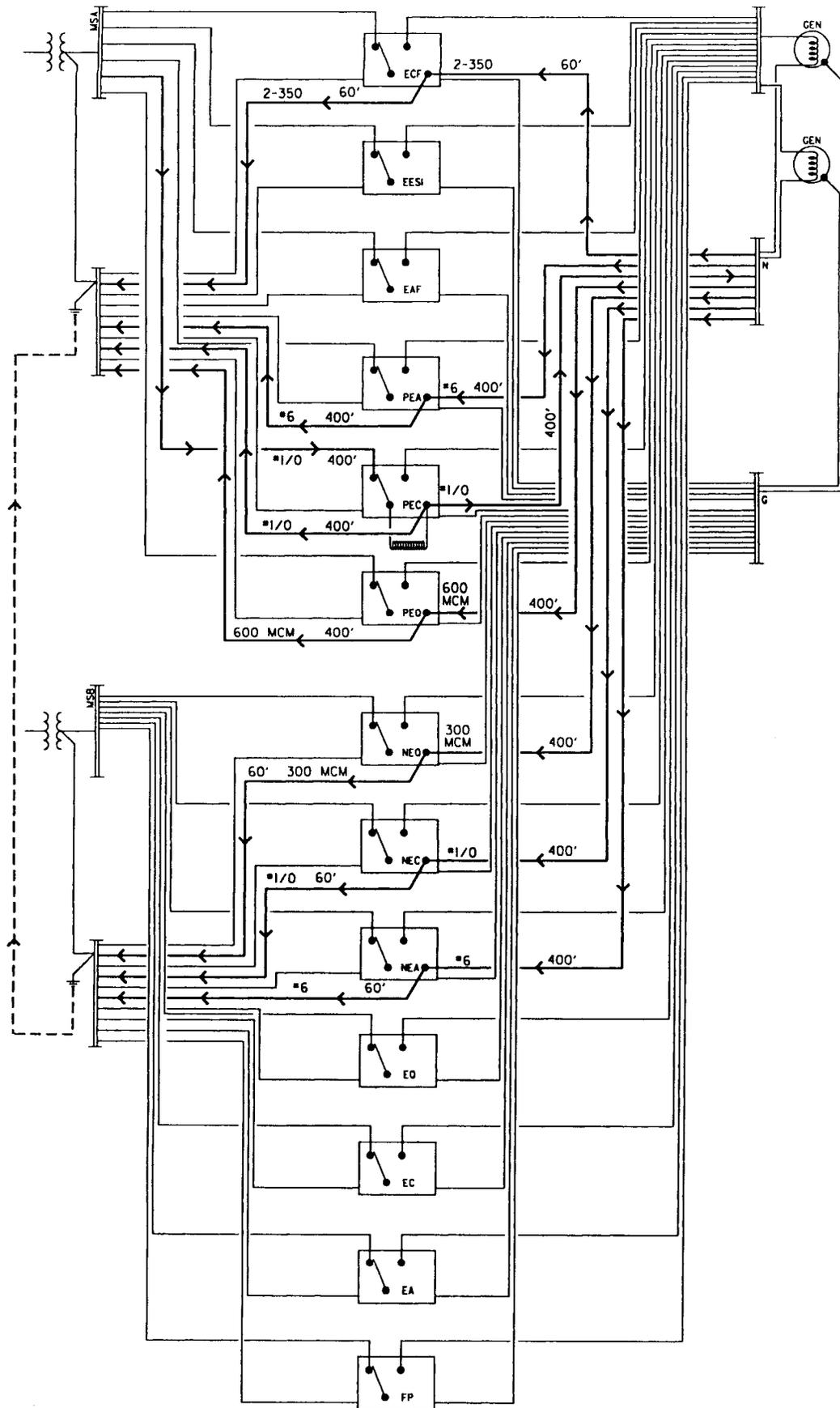


Fig. 14. Hospital case history—two 480Y/277-V services, paralleled generators, and 13 three-pole ATS's.

TABLE II
TRANSFER SWITCH AND GROUNDING OPTIONS FOR SINGLE AND MULTIPLE SERVICES

Services	Generators	Transfer Switches	Comments
Single	Single	3-Pole	Note A
		4-Pole	Note B
	Multiple	3-Pole	Note A
		4-Pole	Note B
Multiple	Single	3-Pole	Note C
		4-Pole	Note D
	Multiple	3-Pole	Note C
		4-Pole	Note D

- NOTE A: Code-complying if generator neutral not grounded at the generator.
 NOTE B: Code-complying if generator neutral(s) grounded at generator(s).
 (4-pole transfer switches are not required unless there is a compelling reason to ground at the generator.)
 NOTE C: Not code-complying.
 NOTE D: Code-complying if generator neutral(s) grounded at generator(s).

VII. CONCLUSION

The following conclusions can be drawn from this study.

- 1) New systems should always comply with the NEC in terms of grounding. Properly grounded systems will prevent intermingling of ground and neutral currents and possible incorrect ground-fault sensing.
- 2) Three-pole transfer switches are generally acceptable for "separately derived systems" consisting of a single service and single generator where the system is grounded at the service only. The "backdoor" neutral currents are likely to be small and are unlikely to produce significant ground-fault sensing problems. However, care should be taken to balance three-phase loads to minimize neutral currents on transfer switches.
- 3) Consideration should be given to the possible future expansion of electrical systems. The electrical design engineer should consider the use of four-pole transfer switches, when an additional service is likely to be added in the future. Establishing a second system ground could ultimately require the installation of four-pole transfer switches.
- 4) In most instances, where permitted by the "authorities having jurisdiction," noncode-complying systems can and should remain in service provided: a) no significant ground currents exist, which might create an electrical safety hazard or drive undesirable common mode currents and b) no significant intermingling of ground and neutral currents exist, and there is no significant threat of ground-fault sensing problems.
- 5) The number of services (and the number of service grounds) is the major consideration in transfer switch selection and the decision to ground (or not to ground) the neutral at the standby generator. The number of standby generators is not a major consideration. Generally, all generators will be grounded or none will be grounded,

depending on the service arrangement and the transfer switches selected.

Table II should be useful to electrical design engineers and others who wish to better understand the grounding/ATS selection problem.

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REFERENCES

- [1] H. O. Nash, Jr., "Ground-fault protection and the problem of nuisance tripping of critical feeders," *IEEE Trans. Ind. Applicat.*, vol. 26, pp. 563-579, May/June 1990.
- [2] R. B. West, "Grounding for emergency and standby power systems," *IEEE Trans. Ind. Applicat.*, vol. 15, pp. 124-136, Mar./Apr. 1979.
- [3] *IAEI Soares Book on Grounding*, 5th ed., J. P. Simmons, Ed., International Association of Electrical Inspectors, Dallas, TX, 1993.



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