Islanding and Overvoltage Considerations in Grounding of Distributed Generation

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Abstract-- The objective of this project was to assess the specific transformer grounding and connection methods that are used at the subject utility for distributed generators (DGs) and provide a risk assessment in terms of potential impact, ways to minimize the impact and site specific screening criteria for additional protection that may be required for DG interconnection. The utility has standardized on a grounded wye – grounded wye transformer connection for customers connected to their distribution system. When a backup generator exists in the customer's facility that could be paralleled with the utility system, a contactor is installed on the neutral to ground connection on the generator. This contactor is opened at any time that the generator is paralleled. The utility is considering remotely dispatching these distributed generation assets in times of peak load in the future. This will require the generators to run paralleled for extended periods of time. Grounding practices for auxiliary generators were evaluated, and time domain simulations of both steady-state and fault conditions were conducted. The most critical factors were found to be assuring that the generator ground switch was closed during islanding and that the overvoltage protection operates correctly to isolate the generator during fault conditions. Recommendations for overvoltage protection and testing were developed based upon the results.

Keywords—distributed generation, generator grounding, generator protection, interconnection protection

I. Introduction

The objective of this project was to assess the specific transformer g[1]rounding and connection methods that are used at the utility for distributed generators and provide a risk assessment in terms of potential impact, ways to minimize the impact and a screening criteria which will be a site specific criteria for additional protection that may be required for DG interconnection. [1,2] Some states have their own specific protection and testing requirements that should be observed.

The utility has standardized on a grounded wye – grounded wye transformer connection for customers connected to their distribution system. When a backup generator exists in the customer's facility (owned by the utility or the customer) that could be operated in such a way as to be paralleled with the utility system, a contactor is installed on the neutral to ground connection on the generator. This contactor is opened at any time that the generator is paralleled. Currently this is a temporary condition, lasting only until the generator comes up to speed. Once this is accomplished, the neutral to ground contactor is closed and the tie switch to the utility system is opened, islanding the customer.

The utility is considering remotely dispatching these distributed generation assets in times of peak load in the future. This will require the generators to run paralleled for extended periods of time. The purpose of this study is to evaluate this transformer connection regarding possibilities of any negative impact on the utility or the customer system and recommend appropriate cost-effective strategies for mitigation if the impact assessment shows cases where it is possible for negative impact under certain realistic conditions.

II. Grounding of Auxiliary Generators

Auxiliary generation systems are divided into two types, fully supplied or partially supplied by the on-site generation. Grounding systems can be classified according to whether the supply transformer is owned by the utility and the system must be grounded at the service entrance (service supplied) or whether there is no connection with another system (separately derived) [5, 9].

1. A full system is shown in Fig. 1. The transformer fed system is service-supplied. The generator system is not separately derived, but is not supplied by the service either. Grounding should be applied at the service equipment and the supply transformer.

2. An example of a separately derived full system is shown in Fig. 2. The generator system is not separately derived. Grounding should be at one point, anywhere between the source and the first disconnecting means or overcurrent device.

Some examples of partial systems that may be found in general use are:

Service-supplied systems (Fig. 3) have the supply transformer owned by the utility. In this case, the service entrance equipment must be grounded. Equipment grounding conductors are connected back to the service entrance equipment. If the generator neutral also goes back to be grounded at the transformer, then the generator is part of the

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service-supplied system. The utility supply transformer will also have its wye-connected secondary winding solidly grounded. A grounded conductor will connect the transformer neutral and the service entrance equipment.

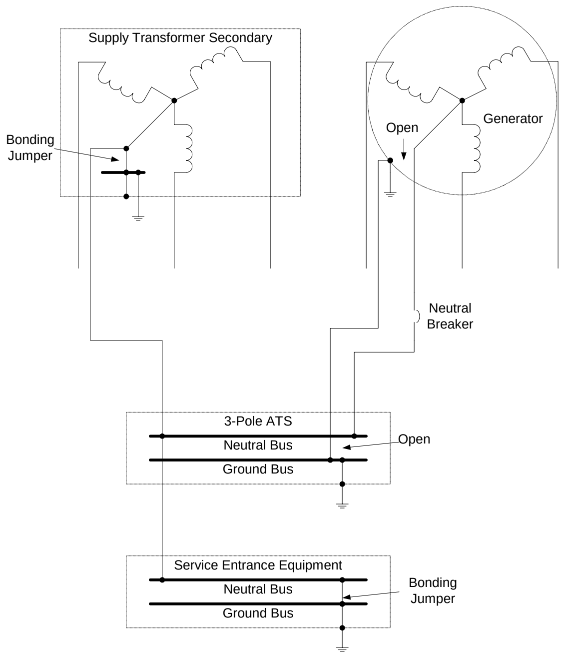


Fig. 1. The utility owned transformer feeds a service-supplied system. The generator does not feed a separately derived system. The ATS is before the service entrance.

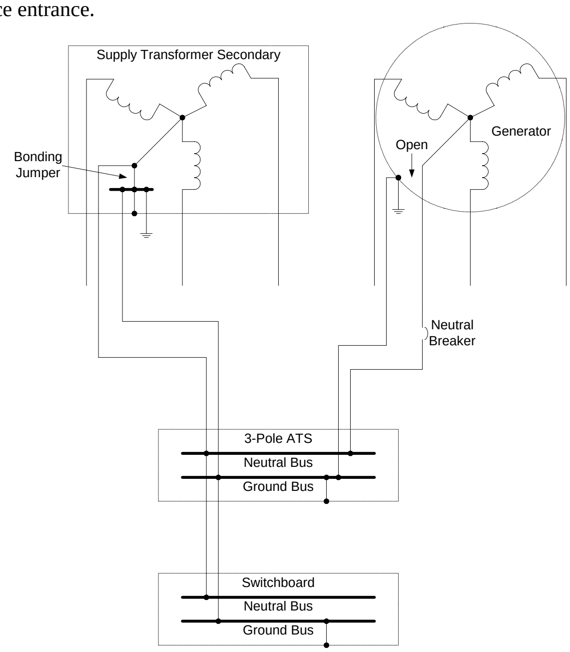


Fig. 2. The transformer feeds a separately derived system, while the generator does not. The switchboard at the building entrance is not a service.

Separately derived systems (Fig. 4) do not have a connection to the other system in any of the phase or neutral conductors. This example could occur inside a customer facility.

A service supplied transformer system may be combined with a separately derived generator system (Fig. 5). This is a fairly common arrangement.

There are two main types of ATS. These are three-pole and four-pole. In three-pole switches, the neutral is connected directly through the switch and only the three phase conductors are switched. The system neutral should be grounded at the source, which will be the service entrance and/or the supply transformer. The generator neutral should be ungrounded. (Fig. 1 and Fig. 3) In four-pole switches, the neutral is switched as well. The generator-supplied system is then a separately derived system, and the generator neutral should be grounded. (Fig. 4)

The automatic transfer switches used in the subject utility have the following characteristics:

1. Three pole operation. The neutral is switched separately and not in the same manner as the phases as in a four pole switch.
2. Closed Transition. The generator contacts close before the line contacts open (and vice-versa) during a transfer of power.
3. Soft Start. An automatic synchronizer controls the closing of the contactors. This reduces synchronization transients.
4. Added time-delay relay (physical or programmed in PLC) to the open generator neutral breaker if the sources are paralleled for > 1 minute. The significance of the neutral breaker will be discussed in a later section.

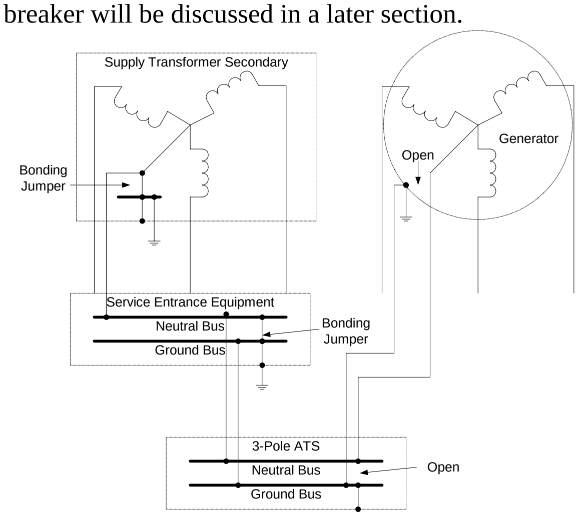


Fig. 3. The generator is part of the service-supplied system. There are no neutral to ground connections downstream of the service entrance.

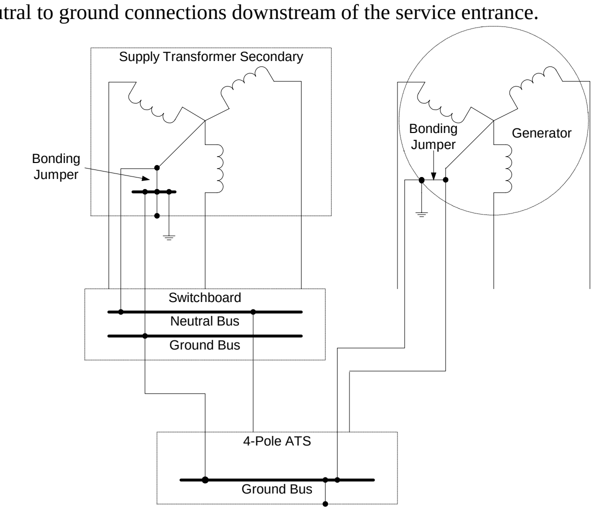


Fig. 4. The generator supplies a separately derived system. The customer owned transformer also supplies a separately derived system. The four-pole transfer switch provides isolation.

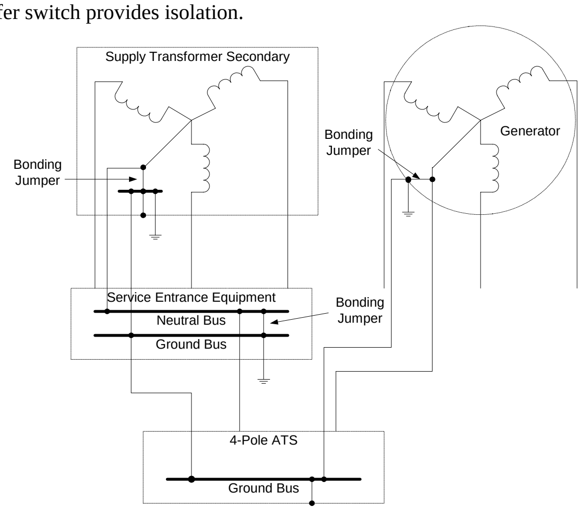


Fig. 5. The generator supplies a separately derived system. The utility owned transformer feeds a service-supplied system. The four-pole transfer switch provides isolation.

For steady state paralleling of the generator with the transformer, the preferred arrangement is with the generator connected before the service entrance. In the arrangements of Figs. 3, 4 and 5 the generator can only supply part of the facility load. In a paralleling situation, there could be back-feed through feeders and service entrance equipment. If support from the on-site generation were required, a better alternative would be for the facility to simply supply that portion of its load from the generators, thus reducing its dependence on the utility.

III. Simulation Results

Simulations were run for both 120 and 480 V systems. The grounding scheme is identical in either case. Simulations were performed with an electromagnetic transient analysis program (PSCAD) in order to model the grounding and neutral details which cannot be captured in a standard short circuit analysis computer program [10]. The generator was modeled as a voltage source behind subtransient impedance in a flat simulation from which rms currents were calculated. Detailed transient modeling of the generator was not necessary in order to obtain the short circuit currents. The grounding scheme is identical in either case. The following cases were examined:

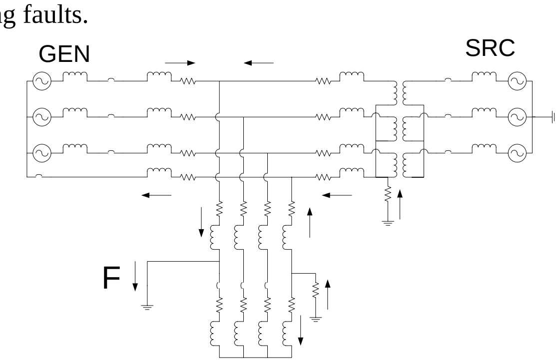
1. Loads supplied by generator in parallel with utility source. This situation occurs when the generator is paralleled and during closed transition transfers. If the loads and sources are balanced, there are no neutral currents flowing. The results are the same with or without the generator neutral breaker open. If the loads are unbalanced, significant neutral currents circulate between the generator and transformer, which are eliminated if the generator neutral to ground connection is opened.

2. Loads supplied by generator alone, with utility source opened. If the loads and sources are balanced, there are no neutral currents flowing. The results are the same with or without the generator neutral breaker open. When the generator is acting in the islanded mode with a four-wire facility load, the neutral breaker should be closed in order to supply the load.

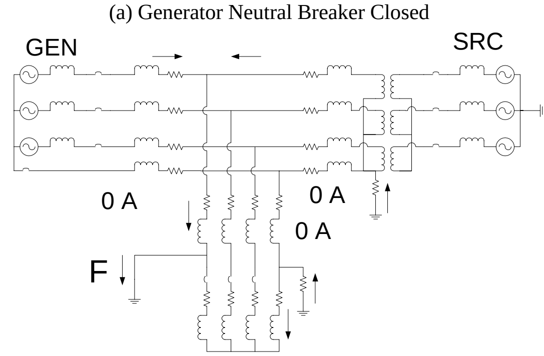
3. Loads supplied by generator in parallel with utility source with unbalanced voltage. The ATS utility breaker will trip for unbalanced voltage if the deviation exceeds the set-point value of 5% negative sequence voltage. The unbalanced voltage results in unbalanced phase currents and neutral current flow. Current unbalance trips could also result. Because the system is grounded at both the transformer and the service, some of the unbalanced neutral current may flow through the parallel ground path if the ground resistance is low. The ground current is greatly reduced when the generator neutral breaker is opened, because the low impedance path through the generator is removed. In multigrounded neutral utility systems, a portion of the unbalanced load current is permitted to flow in the ground. [4]

4. Loads supplied by generator in parallel with utility source with one open phase. This results in a similar situation as a voltage unbalance, but with different values of currents and voltages.

5. Phase to ground fault on the low voltage side. (Fig. 6) The ground current will return through the transformer and service grounds. If the generator neutral is grounded, then return current will flow back into the generator through the neutral. Opening the generator neutral reduces the total ground fault current. However, all of the fault current must then return through the transformer ground. If the generator neutral is opened during islanding, overvoltages may occur during faults.



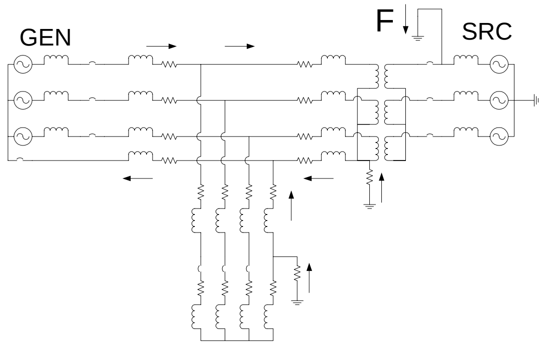
(a) Generator Neutral Breaker Closed



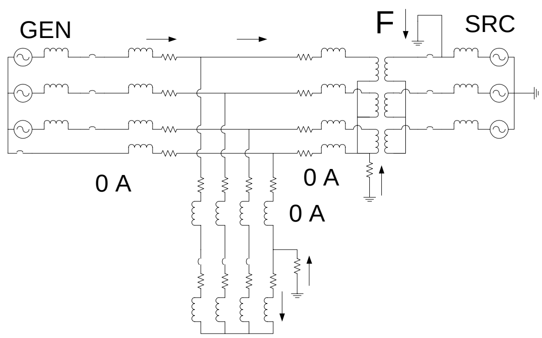
(b) Generator Neutral Breaker Open

Fig. 6. Low Voltage Fault Diagrams.

5. Phase to ground fault on the high voltage side. (Fig. 7) Ground return currents will flow in the low voltage side, returning to the generator if its neutral is grounded, and to the transformer. The magnitudes of these currents on the low voltage side are less than for the low voltage fault.



(a) Generator Neutral Breaker Closed



(b) Generator Neutral Breaker Open

Fig. 7. High Voltage Fault Diagrams.

These calculations were done assuming low resistance ground. If the ground resistance is higher (up to 25 Ohms is allowed by Code) the ground fault currents will be less and the phase to ground voltages greater.

Opening the generator neutral has the following beneficial effects:

- The circulating currents, which occur under unbalanced conditions, are eliminated.
- The generator no longer contributes ground fault current, reducing the severity of faults.

In applications of this type, temporary overvoltages may occur during switching and fault clearing operations due to breaker opening times and other unavoidable delays. The equipment and devices used in these installations should be able to withstand phase-to-phase voltages applied phase to ground during these intervals.

If the generator is supplying the load in the islanded mode, the neutral breaker should be closed, both to supply the load and to avoid overvoltages during ground faults. In larger systems, islanding may occur due to remote switching operations, which should also result in closing of the neutral breaker. Transfer tripping is recommended in these cases [2]. In order to prevent the generator from ungrounded operation; the neutral breaker should close if the generator breaker opens.

IV. Over Voltage Protection

The paralleled generator may be subject to both transient and steady state overvoltages. Provision should be made to protect the unit against both types.

When paralleled, the generator becomes a part of the utility system. This means that it becomes subject to the same transient overvoltages, caused by lightning and switching surges, as other permanently connected equipment [3]. The connection distances between the generator and the nearest surge arrester protected equipment are such that separate protection should be provided for generators. The normal form of protection would consist of surge capacitors to attenuate the slope of fast wavefronts and surge arresters to reduce the magnitude of transient overvoltages. The exact types and ratings to be used are dependent upon system voltage and generator characteristics. It is recommended that the generator manufacturer be contacted for recommendations.

Overvoltages that may last for longer periods include those caused by ground faults, accidental contact with higher voltage systems and overexcitation. In many cases, these will be removed by overvoltage protection in the transfer switch, opening the generator side breaker. If there is a ground fault on the generator side of the breaker the overvoltage will remain after the breaker is opened. Most generator windings, connected line to ground are rated for line to line voltages, but voltage on the generator windings may exceed line to line voltage in the case of an arcing fault and a floating generator. Closing the neutral breaker, returning the generator to a solidly grounded state, can reduce the phase to ground voltages to normal levels. The generator may still be subject to a short time overvoltage.

Consideration should also be given to the generator circuit breaker, which should have a full line-to-line voltage rating, such as 480 V, and not line to neutral ratings, such as 480Y/277V. [6]

The protection equipment, whether part of the ATS, circuit breakers or separate protective relays, should meet applicable surge voltage withstand standards [11].

V. Testing

A testing program should be established with established test procedures, maintenance intervals and training. [7, 8] Tests should be conducted on all critical equipment, including, but not limited to, the ATS and circuit breakers. Testing intervals depend upon the type of equipment, its environment, and the critical nature of its application. The protective relaying functions of the ATS Closed Transition Soft Load controller used for paralleling distributed generation should be tested. The recommended testing interval for circuit breakers in UPS systems is every two years [5]. Recommended tests can be found in IEEE Std. 1015-1997 [6]. These are in addition to the regularly scheduled testing of the emergency generation system and ATS.

VI. Conclusions

In applications of this type, temporary overvoltages may occur during switching and fault clearing operations due to breaker opening times and other unavoidable delays. The equipment and devices used in these installations should be able to withstand phase-to-phase voltages applied phase to ground during these intervals.

Paralleling of generators supplying only a portion of the facility is not recommended. They can be used to reduce total load if necessary.

If the generator is supplying the load in the islanded mode, the neutral breaker should be closed, both to supply the load and to avoid overvoltages during ground faults. In larger systems, islanding may occur due to remote switching operations, which should also result in closing of the neutral breaker.

In order to prevent the generator from ungrounded operation, the neutral breaker should close if the generator breaker or transfer switch opens.

The generator should be protected against transient overvoltages by the application of suitably rated surge arresters and capacitors.

The generator circuit breaker should have a line-to-line voltage rating, such as 480 V, and not a line to neutral rating such as 480Y/277V. This is necessary to interrupt ground faults when the neutral breaker is open.

The protection system in the transfer switch and the low voltage circuit breakers should be tested prior to installation and on a regular maintenance schedule.

The over/undervoltage protection should be conFig.d to sense phase to ground voltages.

VII. Acknowledgements

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VIII. References

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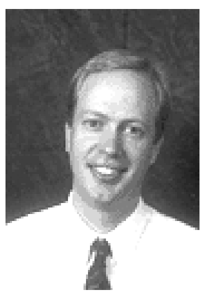
IX. Biographies

Peter E. Sutherland (S'77–M'79–SM'97) received the A.S. degree in Electrical Engineering Technology and the B.S. degree in Electrical Engineering from the University of Maine, Orono, the M.Sc.E. degree in electrical engineering from the University of New Brunswick, Fredericton, N.B., Canada, and the Ph.D. degree in Electric Power Engineering at Rensselaer Polytechnic Institute, Troy, NY.

In 1987, he joined General Electric Company, Schenectady, NY, and held a variety of positions, becoming a Senior Engineer in the GE Power Systems Energy Consulting Department. In 2001, he joined SuperPower, Inc., Schenectady, N.Y., where he worked on applications of superconductivity to electric power systems. In 2003, Dr. Sutherland joined EPRI PEAC Corporation's Schenectady, NY office as a Consulting Engineer. Author of numerous technical papers, he is active in the IEEE Industry Applications Society, and in the IEEE Schenectady Section. Dr. Sutherland is a member of Phi Kappa Phi, Eta Kappa Nu and Tau Beta Pi. He is a Registered Professional Engineer in Pennsylvania, Maine and New York.



Tom Short (tshort@epri-peac.com) is a senior engineer with EPRI PEAC in Schenectady, NY. Before that, he worked for Power Technologies, Inc. for ten years. For several utilities, Tom has performed lightning protection, voltage sag, flicker, capacitor application, and load flow analysis studies and has been involved in several monitoring projects on distribution systems. He received an MS EE degree from Montana State University in 1990. As chair of the IEEE Working Group on the Lightning Performance of Distribution Lines, he led the development of IEEE Std. 1410-1997; for this effort, he was awarded the 2002 Technical Committee Distinguished Service Award. Recently, Mr. Short completed the Electric Power Distribution Handbook, published by CRC Press (2004).