A COMPARISON OF GROUNDING TECHNIQUES FOR DISTRIBUTED GENERATORS IMPLEMENTED IN FOUR-WIRE DISTRIBUTION GRIDS, UPS SYSTEMS AND MICROGRIDS

Annick DEXTERS, KHLim – Belgium, annick.dexters@khlim.be
Tom LOIX, K.U. Leuven - Belgium, tom.loix@esat.kuleuven.be
Johan DRIESEN, K.U. Leuven – Belgium, johan.driesen@esat.kuleuven.be
Ronnie BELMANS, K.U. Leuven - Belgium, ronnie.belmans@esat.kuleuven.be

ABSTRACT

This paper starts with an overview of the common grounding techniques used in distribution grids. Next some important issues and problems related to grounding of distributed generators implemented in these grids will be described. Two applications will be discussed in detail: UPS systems and microgrids. The presence of a neutral conductor in these systems and the ability to operate both in grid-connected and islanded mode complicates the grounding system design. The grounding requirements need to allow correct operation in each of the two operating regimes.

INTRODUCTION

Electric power systems require two types of grounding: system grounding and equipment grounding. The function of system grounding is to limit voltages due to lightning, line surges or unintentional contact with higher voltage lines, as well as stabilizing the voltage to ground during normal conditions. Equipment grounding must assure a low potential difference between nearby metallic frames to protect people from electric shock and protect property from being damaged, and facilitates the operation of circuit protective devices for ground fault currents.

The deregulation of utilities, the emerging power markets and the Kyoto protocol all tend to increase the penetration of distributed generation (DG). Small DG units are connected at the distribution level of the utility system near the customers. Introducing additional generators at this level causes a redistribution of both load and fault current, and adds a possible source of overvoltages. The utility circuits were designed as a radial system, in which fault clearing is achieved by opening only one protective device because there is only one source contributing to the fault. In the presence of DG, there are multiple sources and opening of the utility breaker only does not guarantee that the fault is cleared. Therefore, DG is often required to disconnect from the system when a fault is detected in order to revert to a true radial system and be able to proceed with the normal fault clearing procedure. It is possible that the DG units disconnect either too soon or too late, resulting in detrimental impacts on the distribution system. In both cases, there are potential operating conflicts with respect to overcurrent protection and voltage restrictions [1].

THE COMMON GROUNDING TECHNIQUES IN DISTRIBUTION GRIDS

In case of a single power source, grounding is relatively straightforward. In radial distribution grids this condition is fulfilled. A grounded distribution system is usually derived from a distribution substation transformer with Y-connected secondary windings. The neutral point of the windings can be solidly grounded or connected to ground through a current-limiting device such as a resistor or reactor. Alternatively, a grounding transformer may be used to establish a grounded system. In four-wire distribution systems, the neutral conductor is either connected to earth several times (*multigrounded*), which is characteristic for many MV grids in US and LV grids in Europe, or fully insulated, being only connected to earth at the source (*unigrounded*). In three-wire unigrounded systems, e.g. the MV grids in Europe, a neutral conductor is not run with each circuit, but the system is grounded through the connections of the substation transformer or grounding transformer.

Each method of grounding has its own advantages and disadvantages. One can roughly state that as the single fault-to-ground current decreases due to current-limiting devices, the overvoltages on the unfaulted phases reach a higher value and the sensitivity of the fault detection must be increased. These overvoltages can result in power quality problems and failure of arresters [2].

Systems rated 600V or less are always solidly grounded to facilitate overcurrent device operation in case of ground faults. The prevailing practice in US is to connect the utility neutral to the equipment ground of the customers. In Europe on the other hand, one distinguishes the TT, TN and IT systems where the utility neutral and the equipment ground are not necessarily bonded (IEC 60364).

GROUNDING OF DG UNITS

An important share of the present DG units uses a synchronous generator. One must pay attention when choosing the type of grounding, since it is not always recommendable to solidly ground the neutral of the generator.

In case of a stator ground fault extensive damage can occur to the generator, even after opening the circuit breaker. This damage is due to the time required for the excitation field to decay, thereby maintaining the flow of current to the fault Third harmonic currents, driven by the third harmonic voltage inherent to the generator, can circulate in the power system zero sequence network. The magnitude of these currents can be reduced by a proper neutral grounding device or a generator with a 2/3 winding pitch.

The ground fault current from a solidly grounded generator is larger than the three-phase fault current since the natural zero sequence impedance of a synchronous generator is typically about half the subtransient positive sequence reactance [3]. Therefore the appropriate technique of grounding standard generators is inserting an impedance between the neutral point and earth or grounding the interconnection transformer.

Several winding arrangements for interconnection transformers are possible: Δ-grounded Y, Δ-Δ, grounded Y-Δ and grounded Y-grounded Y, each of which has its advantages and disadvantages, depending on the grounding technique of the utility. Here the focus is on the fault contribution and overvoltages for DG units coupled to a four-wire multigrounded distribution grid.

Figure 1 shows several single line-to-ground (SLG) fault locations. In case the primary winding on the utility side of the interconnection transformer is not grounded, the DG unit does not supply any ground fault current for a fault at F1 or F2 (at least when the DG is decoupled before the utility breakers are opened). If the primary winding is a grounded Y, the DG unit can backfeed the distribution feeder, which might be a serious problem, certainly in four-wire multigrounded distribution grids.

A grounded Y-Δ transformer creates additional ground current paths as is depicted in Figure 2. The fault currents are no longer flowing just in one path from the substation to the fault, but in several parallel paths even downstream of the fault. This can result in malfunctioning of protective relays and needlessly blowing line and transformer fuses.

One common side effect is that the feeder breaker will trip for any SLG fault on all feeders served from the same substation bus. The utility transformer might be overstressed repeatedly and eventually fail. In order to prevent the sympathetic tripping of the feeder breaker for SLG faults on other feeders directional overcurrent relays can be used [1].

To understand how a DG unit can create an overvoltage during ground fault, consider an interconnection transformer with a Δ winding on the utility side as depicted in Figure 3. A permanent SLG fault has occurred and the

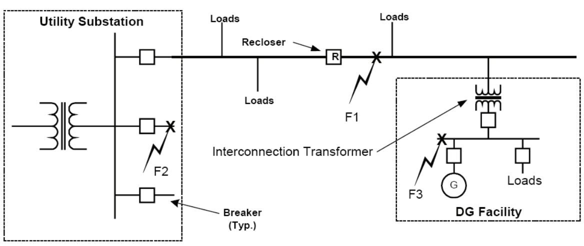

Figure 1: Overview of SLG fault locations

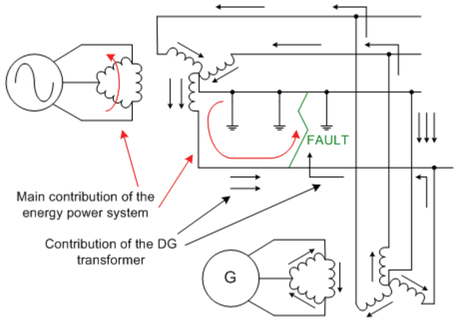

Figure 2: SLG fault contribution of a DG unit

utility interrupting device has opened before the DG was disconnected. This leaves an isolated system energized by the DG unit. There is no longer a grounded source on the utility side of the transformer. Now the potential of the neutral essentially equals that of the faulted phase. Any loads or voltage arresters connected between an unfaulted phase and neutral are subjected to a line-to-line voltage, as is shown in Figure 3. This could damage the loads after just

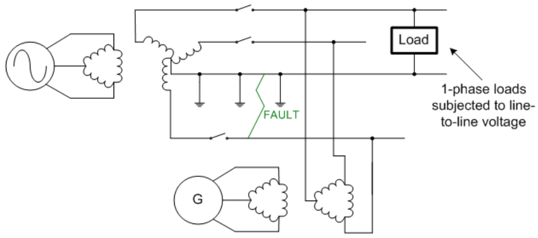

Figure 3: Load voltage rating violation

a few cycles. However the overvoltage magnitude decreases significantly in case the DG unit is not strong enough to feed the islanded network [4].

Using interconnection transformers is the prevailing practice for connecting medium-power DG units in parallel with the MV distribution grid. Low-voltage synchronous generators on the contrary may be solidly grounded not only in island mode but also in grid-connected mode They typically appear to have sufficient bracing and a 2/3 winding pitch to permit this. Solidly grounding is however not possible for asynchronous generators because of third harmonic currents associated with this type of generator. However, the main considerations formerly discussed are also valid in case of a direct connection of these generators to the utility grid.

GROUNDING OF UPS SYSTEMS

Installing a UPS system is the most common way to ensure a very reliable and high quality power supply to sensitive loads, such as computer data centers or telecommunication centers. These kinds of loads are very sensitive to disturbances of the power supply parameters, mainly the voltage amplitude and frequency, from their rated values as well as a (temporary) loss of power supply. Using a UPS system for these loads enables to protect these loads against grid disturbances and ensures continuous operation of the loads, avoiding expensive shutdowns and restarts.

One important aspect of designing a UPS system is grounding. When the grounding is poorly implemented, serious problems might arise, resulting in seriously degraded performance, which is quite the opposite of what one has in mind when installing a UPS system. The discussion of grounding techniques for UPS systems given below focuses on on-line static UPS systems. However, the main considerations and conclusions are also applicable to rotary UPS systems.

It is important to note that an on-line UPS system usually has at least two different operation modes: one in which the loads are fed by the UPS power electronic converter(s), the other in which the loads are fed by the utility grid (when the UPS bypass is closed). Implementing a grounding strategy operating well in both modes is necessary to provide a high level of power supply to the loads at all times.

On-line static UPS system topology

Figure 4 shows the UPS system topology used in this paper to outline the main grounding issues and solutions for UPS systems. The building including sensitive loads is connected to the medium-voltage utility grid using several transformers. Also emergency diesel generators are installed, able to feed the loads in case of a black-out in the utility grid. The transformers and emergency generators are connected to two distribution busbars, as well as the input rectifiers of the UPS systems and the static (and possibly also manual) bypass switches. The output of the UPS inverters is connected to an LC-filter and subsequently to a Static Transfer Switch (STS). It is also possible to connect the UPS system outputs to several load distribution busbars, which in turn are connect to the STSs. Each group of loads is connected to the output of an STS, being able to be fed by two parallel and independent UPS systems (and possibly the utility grid, in case the "active" UPS system works in bypass mode).

When choosing the type of grounding system for a UPS system, the IT system is sometimes preferred because of its enhanced continuity of power supply, even during the presence of the first fault. The fault has to be found and eliminated before a second fault occurs. Here a TN-S grounding system is chosen, which is often preferred for installations with an important amount of (power) electronic loads and associated EMI filters [5].

Main grounding issues for a UPS in a TN-S system

The main issue regarding the grounding of UPS systems is the connection of the neutral conductor to earth. It is crucial to make this connection only once, otherwise an undesirable intermingling of ground and neutral currents might occur, resulting in unwanted voltages, which are capable of driving common mode currents, and incorrect ground-fault sensing. This is completely the opposite of the prevailing practice of multigrounding the neutral of four-wire distribution grids.

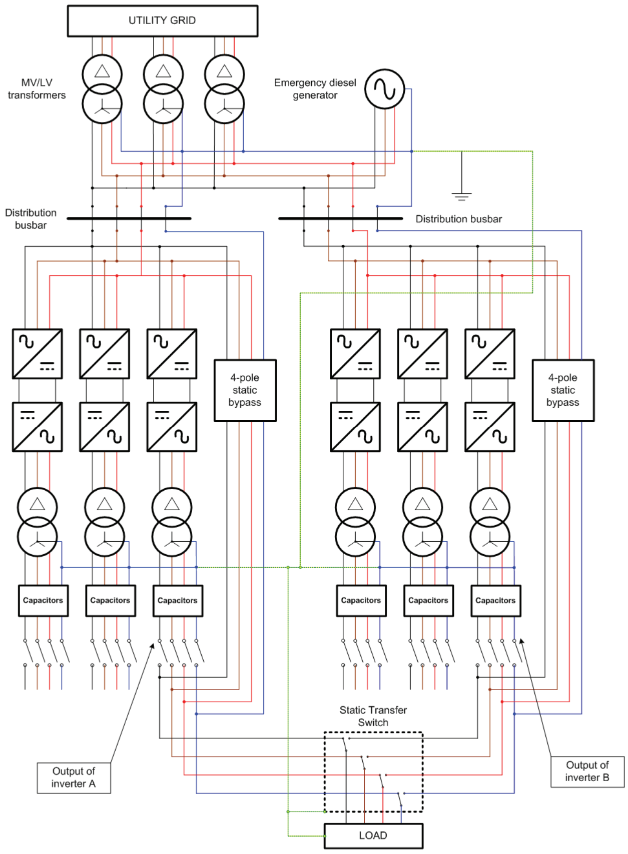

Figure 4: On-line static UPS system

Figure 4 shows two points at which the neutral conductor is connected to earth: one at the neutral point at the secondary side of the transformers (as well as the emergency generator), upstream of the UPS system converters and one at the output of the converters. While the first point provides an earth link in case the loads are fed by the utility grid (through the static bypass switch), the second one provides an earth link when the loads are fed through the power electronic converters. It is vital to use 4-pole static bypass switches and 4-pole switches at the output of the converter filter, in order to avoid a double connection of the neutral conductor to earth, which would result in a loop formed by the neutral and earthing conductors. It is also important to use 4-pole STSs in this topology [5],[6]. In case one just connects the neutral conductors of the two parallel sources feeding the STS (as is done in a 3-pole STS), another neutral and ground conductor loop appears.

Simulation results

This section describes some simulation results, obtained using Matlab®-Simulink and the PLECS toolbox, concerning a UPS topology similar to the one shown in Figure 4. The main differences between the topology used for the simulations and the one depicted in Figure 4 are the use of three-pole static bypass switches, effectively connecting the upstream neutral conductor with the neutral conductor started at the secondary side of the inverter output transformers, the use of a three-pole STS. This situation is actually witnessed in several buildings. The load varies between a balanced total of 96 kVA and an unbalanced total of 160 kVA.

An important issue illustrated here is the occurrence of stray currents, due to the existence of several parallel paths for the neutral current, which might be large due to the important share of single-phase loads and the amount of unbalance associated with them. Figure 5 shows the currents through two neutral conductors in case the load is varied one phase at a time. Inverter A (see Figure 4), supplying the loads and its neutral current is shown in the uppermost part of Figure 5. The current through the neutral conductor of inverter B (Figure 4), connected to the same 3-pole STS, is shown in the lower part of Figure 5. One can see that an important amount of the neutral load current returns through the neutral conductor of inverter B and the earth conductor connecting the neutral point of inverters A and B. There are even more possible paths for the neutral load current, for instance through the neutral conductors starting at the distribution busbars, which are always connected to the neutral conductors at the inverter output in case one uses 3-pole static bypass switches and no isolating transformer in the bypass channel, and through the grounding conductors.

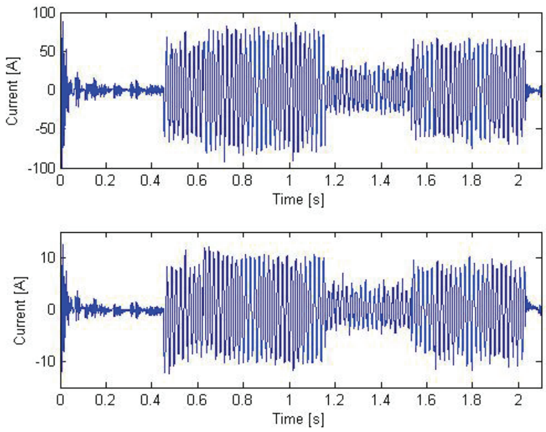

Figure 5: Neutral currents in case of unbalanced load

The presence of stray currents might cause malfunctioning ground-fault protection (GFP), in case the protective devices monitor the three phase conductors and the neutral conductor. The part of the neutral current returning through the grounding system is not seen by the GFP, so the system might be shut down because the GFP mistakenly suspects the presence of an earth fault. Conversely, in case of an earth fault occurring on one of the live conductors, part of the fault current might return through the neutral conductor. The GFP "sees" a smaller fault current than the one actually present and might decide not to open the circuit breakers.

It is clear that both safety and continuity of supply might be significantly reduced when using 3-pole STSs and static bypass switches in a UPS topology with a TN-S grounding system. Application of the structure depicted in Figure 4 allows eliminating these errors and guarantees correct operation under all circumstances.

GROUNDING IN MICROGRIDS

The MicroGrid concept [7] has received much attention as it offers a way to both support the growing penetration of distribution generation and increase the reliability and continuity of electricity supply to customers. A microgrid consists of a group of local (distributed) generators and loads (e.g. a city district or an industrial estate), which are normally connected to the utility grid, but are also able to operate in island mode (disconnected from the utility grid). The MicroGrid must achieve the same level of safety as any other conventional distribution system in both modes.

According to current legislation, LV generators may be earthed or unearthed when operating in parallel with the distribution system. The usual practice is not to earth the generator neutral point in parallel operation because the earthing of several generators dispersed in the MicroGrid hampers control of earth fault currents, detection of earth leakage current and avoiding interference to communication systems. In that case an earth reference point must be provided when the MicroGrid is disconnected from the main grid. One possible solution is to operate a generator with an unearthed star point when grid-connected and then automatically reconnect the star point to earth when the MicroGrid is islanded. A more evident solution is using the source earth of the distribution transformer. So, a MicroGrid should be disconnected from the main grid only by opening the circuit breaker upstream from the transformer. Then the micro-sources could be operated safely without earthing their neutral points locally [8].

REFERENCES

[1] R.C. Dugan, T.E. McDermott, "Distributed generation", *IEEE Ind. Appl. Mag.*, March/April 2002, pp. 19-25.

[2] J. Burke, M. Marshall, 2001, "Distribution system neutral grounding", *Proc. of the IEEE Transm. and Distr. Conf. and Exp.*, vol.1, 2001, pp. 166-170.

[3] P. Pillay et al., "Grounding and ground fault protection of multiple generator installations on medium voltage industrial and commercial power systems- Part 2: Grounding Methods", *IEEE Tr. on Ind. Appl.*, vol. 40, No. 1, January/February 2004, pp. 17-23.

[4] P. Barker, "Overvoltage Considerations in Applying Distributed Resources on Power Systems", *Proc. Of the 2002 IEEE PES Summer Meeting*, vol. 1, pp. 109-114.

[5] J.-N. Fiorina, "Uninterruptible Static Power Supplies and the Protection of Persons", *Cahier Technique no. 129 (Collection Technique de Schneider)*.

[6] H. O. Nash, "More about Standby Generator Grounding, GFP, and Currents that Go Bump in the Night", *IEEE Tr. on Ind. Appl.*, vol. 33, No. 3, May/June 1997, pp. 593-600.

[7] R. H. Lasseter and P. Piagi, "Microgrid: A Conceptual Solution", *Proc. of the 35th Annual IEEE Power Electronics Specialists Conf.*, Aachen, Germany, June 20-25, 2004, pp. 4285-4290.

[8] N. Jenkins et al., "Safety Guidelines for a MicroGrid", *Deliverable DE1, Internal report for MicroGrids project*, Nov. 2004.