Ground Fault Protection for the ACH550

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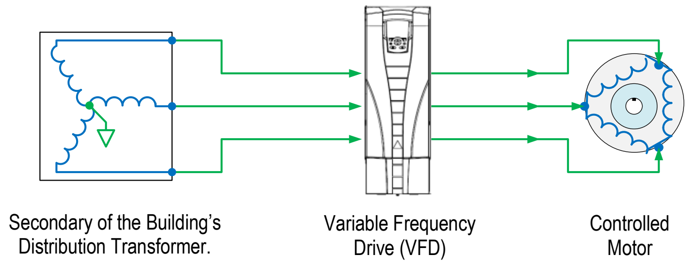
Introduction to Short Circuit Protection

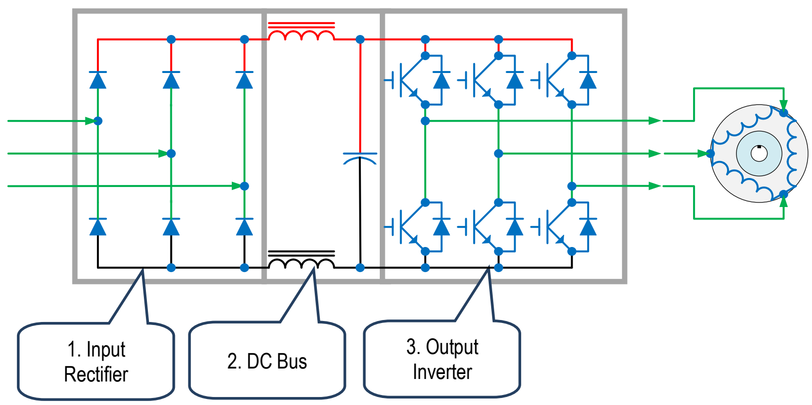


A variable frequency drive (VFD) is generally powered by branch of building's power grid which is referenced to earth ground. If a ground fault occurs between the output of the transformer and any branch circuit that it powers, the fault current that flows will trip the ground fault protection device in the appropriate branch circuit. This is done to protect the building from catastrophic damage.

In a similar way, a short circuit in the output of the VFD (either in the motor or in the wiring between the VFD and the motor) could cause significant damage in the VFD and possibly damage to the building. For this reason, ground fault protection is provided in VFDs.

The Impact of a Ground Fault on a VFD

A modern VFD has three main parts.



1. A full-wave bridge rectifier, which converts the incoming AC into DC.
2. A DC bus, which filters the output of the rectifier to reduce electrical noise transfer between the AC power line and the VFD. The DC bus capacitors also store electrical energy so that it can be delivered to the motor as required. In some VFDs, DC chokes are included to provide additional filtering between the AC power line and the VFD bus.
3. An inverter section, which uses six insulated gate, bipolar transistors (IGBTs). This switches the energy that is stored in the DC bus capacitors to the motor as required. Each motor lead from the three-phase motor is connected to a pair of IGBTs. One of these IGBTs is connected to the positive side of the DC bus and the other is connected to the DC bus's negative side. In this way, each motor lead can be individually controlled to receive the required voltage and current for efficient control of the motor's speed.

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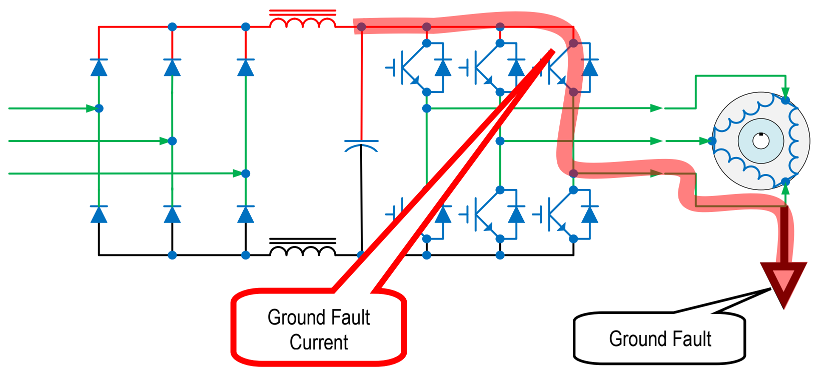
Because the input AC voltage is at a high voltage with respect to earth ground, the DC bus will be at a high voltage with respect to earth ground. As a result, any ground fault in the output of the VFD will attempt to quickly produce a very large fault current.



Notice that this fault current may follow a path through only one of the inverter's IGBTs. This can result in a large stress on this specific IGBT and so can cause potentially irreversible damage to the VFD's inverter section.

<u>**Considerations for Ground Fault Protection**</u>

It is clear that the only way that a VFD can interrupt a ground fault is to turn OFF its inverter IGBTs. Because an IGBT can switch current very quickly and because it is quite rugged, in most situations this is sufficient to protect the VFD, as long as the fault current hasn't risen too high before the IGBTs are shut down.

The rate of rise of a current that is produced by an abrupt change in voltage depends on the impedance of the current path.

- For normal motor control, the output current from the VFD passes through the motor's windings. These present a relatively high impedance to the current, so the voltage pulse from turning ON the inverter IGBTs won't immediately cause a large peak output current.

  Because of this, the VFD's normal control of the IGBTs, which consists of the VFD's standard current sensors and control based on the VFD's control card and its timing clock, is sufficient.

- In the case of a ground fault, the potential of having the fault current quickly rise to a very high level is real, since the current bypasses the stator coils of the motor. The two important concerns are:
  - **Ground Fault Current Detection Concerns**
    The normal output current detection devices for a VFD generally rely on determining the output current of the VFD by measuring the magnitude of the magnetic field that the motor current creates. This is then converted to a signal that is sent to the VFD's control card. This process slows the current measurement process and injects possible error if the sensor's calibration drifts due to age or ambient conditions.

    A fast, reliable method of detecting a ground fault current is needed.

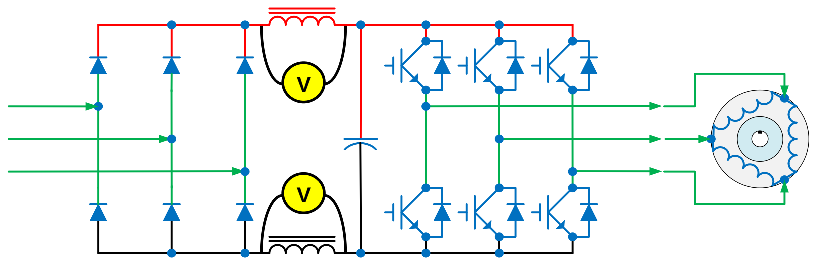
  - **Concerns About the Speed of the VFD's Response**
    In order to be fast enough to turn OFF the VFD's inverter IGBTs, the ground fault protection circuit can't be controlled by the clock of the VFD's control card. Even sending an interrupt to this controller isn't fast enough. The ground fault detection circuit needs to be able to shut down the VFD's inverter as fast as the hardware allows.

    When a ground fault is detected, the VFD must be able to shut down its inverter section very quickly.

Implementing Ground Fault Protection in the ACH550

The following discussions deal with frame sizes through R4 (75 HP at 480 V AC) of the ACH550. Larger sizes of the ACH550 use similar concepts, but different hardware.

- **Ground Fault Current Detection**
  As discussed above, a ground fault results when current that is produced in the VFD returns to earth ground without going through the connected motor. Therefore, most ground fault detection circuits function by comparing the current going out from the VFD to the current that is being returned to the VFD. If these two values do not match closely enough, the VFD will view that a ground fault is present.



  The DC chokes provide an excellent way to detect discrepancies in these two currents. Ohm's Law is the key here. The voltage drop across the choke is proportional to the current through it. Since the two chokes are identical, the voltage drops across each should be identical. If the difference between these two voltages indicates a current discrepancy that is beyond the range of normal leakage current, the VFD's ground fault circuit will be activated. This provides a fast, reliable way to detect ground faults.

  This range of ACH550 VFDs provides additional ground fault protection by using a voltage divider in the VFD's inverter section. The voltage from this circuit indicates if a ground fault is present in the VFD's output before the VFD is started. This keeps the VFD from starting into an existing ground fault.

- **Speed of the VFD's Response**
  The ground fault detection circuit is totally contained in the VFD's power circuitry. It acts directly to shut down the inverter's IGBTs. Once this is accomplished, it takes to time to report the fault back to the VFD's control card.

Reliability of the ACH550's Ground Fault Detection

Experience has shown that the ground fault protection described above reliably protects the VFD from most ground faults. However, there are some unique circumstances where damage to the VFD can still occur.

- One problem comes when the end user continually resets a ground fault without checking into its cause. While the ground fault protection circuit can prevent an immediate VFD failure, the IGBT that was subjected to the fault current will still be stressed. If this is continued, this IGBT will continue to be stressed and a VFD failure is possible. This is particularly the case when the fault is reset and the VFD is quickly restarted into a ground fault multiple times. The internal thermal stress that this imposes on the impacted IGBT can hasten its failure.

- While the sensitivity of a ground fault detection circuit can sometimes cause nuisance trips, in most in stances the cause of such a trip can be found and rectified. To help in the testing needed for such an investigation, the ACH550's software allows the VFD's ground fault protection to be disabled. This should *never* be done casually.

- While the ground fault protection process is quite fast, it can't be infinitely fast. It has proven to be effective in protecting the VFD's power components for the vast majority of ground fault situations because the most common ground fault starts with a small insulation breakdown. Such a breakdown initially presents high impedance path to the fault current. As a result, the ground fault current doesn't rise extremely quickly and the VFD's inverter can be shut down before an extreme fault current occurs.

  A non-typical ground fault can be caused by physical damage that produces an extremely low impedance ground current path. Visible damage to the motor or catastrophic damage to the VFD's inverter section may indication of such a situation. In this case, the fault current may rise to a high level before the VFD's inverter can interrupt the fault current and protect itself. Even in such a case, the VFD will still protect the building from catastrophic damage.