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Ground Fault Protection

The term “low magnitude” arcing ground fault is a deceptive description of this type fault. What is meant by this is that the fault current magnitude is low compared to that of a bolted fault. Even so, the arc energy released at the point of the fault can cause much damage and may result in a fire. A ground fault is an insulation failure between an energized conductor and ground. A phase-to-ground arcing fault, unlike a phase-to-phase bolted fault, is a high-impedance type fault. The factors that contribute to this high impedance are the resistance of the arc and the impedance of the return path. This return path is usually metal conduit, raceway, busway housing or switchboard frames. Another contributing factor is the spasmodic nature of the arc. The circuit breaker or fuse protecting the circuit detects the fault current, but the actual ground fault current magnitude is ever changing due to arc elongating blowout effects, self-clearing attempts and arc reignition.

These current limiting effects make the circuit breaker or fuse incapable of detecting the actual damage that is occurring. This is not to imply that these devices are inadequate. The problem is one of system protection because the circuit breaker must be adjusted (or fuse size selected) so as to hold without tripping under momentary overload conditions, such as motor starting current or transformer inrush current. Therefore, the circuit breaker or fuse cannot open quickly enough under relatively low magnitude faults to limit the arcing damage.

Figure 10 illustrates the basic problem. Shown is a typical distribution system with a 1600 ampere main service entrance unit with a circuit breaker (single line “a”) or fused service protector (single line “b”). A ground fault of 1500 amperes on the bus would affect but would not open either device. A 4000 ampere ground fault would be cleared in approximately 35 seconds by the circuit breaker and in 230 seconds by the fuse. To allow a fault of this magnitude to persist for this length of time would create more than 92,000 kW seconds of arc energy. As a result of tests made, it has been determined that an arc with a value of 1050 kW seconds of energy would vaporize about 1.0 cubic in. of copper or 2.5 cubic in. of aluminum. Obviously a fault of the magnitude shown in Figure 10 could cause a considerable amount of damage.

The nature of low-level arcing ground faults makes impractical their detection by a traditional overcurrent devices. To complete total protection of the system against all possible types of faults, other means are utilized to detect ground fault currents, including:

- **Zero sequence method**
- **Source ground current (or ground return) method**
- **Residual connection method**

**Zero Sequence Method**

This is commonly used when ground fault protection is provided for equipment employing electromechanical trip devices. The scheme uses a core balance type current transformer (ground sensor) which encircles all phase conductors (and neutral on four wire system) to detect ground faults.

The operation of this system is such that under normal operating conditions (e.g., no ground fault on the system) there is no output from the ground sensor to the tripping relay because the vector sum of all the currents through the sensor window is zero.

\[ I_a + I_b + I_c + I_n = 0 \]

If a ground fault occurs on the system, there is now an additional current \( I_g \) seen by ground sensor which returns to the source by a path other than through the sensor window. The sensor now sees an unbalance caused by \( I_g \) and operates the ground relay which trips the circuit protector.

\[ I_a + I_b + I_c + I_n = I_g \]

The ground sensor is located downstream from the point at which the system is grounded and can be mounted either on the line side or load side of the main disconnect device. This method can be used on incoming main disconnect or on feeders.
Source Ground Current (or Ground Return) Method

This method of detecting the ground fault current $I_g$ locates the ground sensor on the neutral connection to ground at the service entrance. This means that the ground sensor only detects ground fault current. This type of detection has some limitations because it is detecting the ground fault return current. On multiple source systems with multiple connections to ground, this ground fault current can return by more than one path, therefore, some sensitivity in detecting these faults would be lost.

Residual Connection Method

Current sensors, one on each of the phase conductors and on the neutral conductors, are connected in common. This common (or residual connection) measures the vector summation of the phase currents and the neutral current. Under normal conditions, this vector summation will be zero, and no current will be applied to the ground relay. If a fault involving ground occurs, the current summation is not equal to zero. Current flows into common connection which is applied to the relay. This method of detecting ground fault current is used in circuit breakers with electronic trip device.

Residual Ground Current Sensing

3-Wire System

This system is used with electronic trip units, and always includes three current sensors mounted on the circuit breaker. A trip element is connected in series with each sensor to provide phase overcurrent protection. By adding a ground trip element in the residual (neutral) circuit of the three current sensors, it will sense ground fault current only, and not load current. This permits more sensitive settings to protect against low magnitude ground faults. This scheme is shown in Figure 14. Under normal conditions, the vector sum of the current in all of the phases equals zero. No current would flow in the GND element, which is also true under the condition of a phase-to-phase fault. A phase-to-ground fault would cause a current to flow in the GND trip element. If the magnitude of this current exceeds the pickup setting for the required time, the trip unit will operate to trip the breaker.
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Ground Fault Protection

4-Wire System
To avoid false tripping, a fourth current sensor is connected in the neutral conductor to sense normal neutral current. This fourth sensor is connected so that it cancels the normal neutral current which is developed in the residual circuit as shown in Figure 15.

Under normal conditions, the vector sum of the current in all phases equals the neutral current. Disregarding the effects of the neutral sensor connection, the neutral current would flow through the GND element. Since this is normal neutral current, pickup of the GND element is not desired. Therefore, the neutral sensor is added to sense the same neutral current as the GND sensor — but opposite in polarity. The result is a circulating current between the phase sensing current sensors and the neutral sensor, with no current flowing through the GND sensor. This is similar to a differential relay circuit. When a phase-to-ground fault occurs, the vector sum of the phase currents will no longer equal the neutral current because the ground fault current returns via the ground bus and bypasses the neutral. If the magnitude of the phase-to-ground current exceeds the pickup setting of the GND element for the required time, the trip unit will operate to open the breaker.

Types Of Coordinated Ground Fault Tripping Systems

There are two types of Coordinated Ground Fault Systems:

- **Time / Current Selective**
- **Zone Selective (Zone Interlock)**

**Time / Current Selective**
In this system the time / current characteristics of the Ground Fault Protection (GFP) devices used with each disconnect are coordinated so that the nearest disconnect supplying the ground fault location will open. Any upstream disconnects remain closed and continue to supply the remaining load current. Each set of GFP devices should have a specified time-current operating characteristic. When disconnects are connected in series, each downstream device should use a time-current setting that will cause it to open and clear the circuit before any upstream disconnect tripping mechanism is actuated. The time-current bands of disconnects in series must not overlap and must be separated from each other sufficiently to allow for the clearing time of each disconnecting means used. The time / current selective system is recommended for applications where damage levels associated with the time / current settings used are tolerable. This type of system does not require interlocking wiring between the GFP devices associated with main feeder and branch disconnecting devices.

**Figure 15. Schematic for Ground Protection on 4-Wire Systems, Residual Sensing**

**Zone Selective (Zone Interlock)**
In this system each disconnecting means should open as quickly as possible when a ground fault occurs in the zone where this disconnect is the nearest supply source.

The GFP device for an upstream disconnecting means should have at least two modes of operation. If a ground fault occurs between it and the nearest downstream disconnect, it should operate in its fast tripping mode.

When a ground fault occurs beyond the disconnect, the downstream GFP device should open in its fast tripping mode and simultaneously send a restraining signal to the upstream device and transfer that device to a time-delay tripping mode. The upstream time-delay tripping characteristic selected should be such that the downstream disconnect will open and clear the circuit before the upstream disconnect tripping mechanism is actuated. The time-current characteristic of the upstream device should be such as to offer backup protection in the event of malfunction of the downstream equipment.

Alternatively, a restraining signal from a downstream device may be used to prevent the tripping of an upstream disconnect on ground fault instead of causing it to operate in the time-delay tripping mode. This may be done where backup protection is less important than continuity of service to critical loads supplied by the upstream unit. There are very few instances in which this is justified, and a careful study of the entire system should be made before using this type of interlocking.

For a zone selective system, the time-current bands of disconnects in series, although used only for backup protection, should not overlap and should be separate from each other sufficiently to allow for the opening time of each disconnecting means used.
The zone selective or zone interlock system provides fast tripping of the nearest disconnect upstream of the ground fault. The damage level is the lowest that is possible because the ground fault is cleared as quickly as the protective equipment can respond and the disconnect can open. Additional interlocking wiring and circuitry for sending and receiving the restraining signals are required.

The zone selective or zone interlock scheme is for those few special applications where exceptionally fast tripping is necessary for all feeders throughout the entire system to reduce damage. Note that although the relay time can be reduced appreciably, the circuit breaker mechanism and arcing time (plus safety margin) will still be present.

Zone Selective Operation (Figure 17):
a) Relay-1 will sense a ground fault at A when it exceeds 10 amperes. It will instantly initiate tripping of the Branch breaker and send restraining signals (transfer from instantaneous operation to time-delayed operation) to Relay-2 and Relay-3 (Relay-2 and Relay-3 will then back up Relay-1 on a time coordinated basis). Relay-4 will be restrained by Relay-2 if ground fault exceeds 100 amperes.
b) Relay-2 will sense a ground fault at B when it exceeds 100 amperes. It will instantly initiate tripping of the Sub-Feeder breaker and send restraining signals to Relay-3 and Relay-4.
c) Relay-3 will sense a ground fault at C when it exceeds 400 amperes. It will instantly initiate tripping of the Feeder breaker and send a restraining signal to Relay-4.
d) Relay-4 will sense a ground fault at D when it exceeds 800 amperes. It will instantly initiate tripping of the Main breaker.

Table 17.1

<table>
<thead>
<tr>
<th>Typical Ampere Setting</th>
<th>Restrained Time Delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td>0.4 SEC.</td>
</tr>
<tr>
<td>400</td>
<td>0.3 SEC.</td>
</tr>
<tr>
<td>100</td>
<td>0.2 SEC.</td>
</tr>
<tr>
<td>10</td>
<td>0.1 SEC.</td>
</tr>
</tbody>
</table>
Ground Fault Protection

Typical Application Diagrams

Figures 18 through 23 on this and the facing page show the basic methods of applying ground fault protection (GFP). Other types of distribution systems will require variations of these methods to satisfy other system conditions. These diagrams show circuit breakers as the disconnects. Any disconnecting means can be utilized, providing it is suitable for use with a ground fault protection system as indicated in the scope of this application guide. The examples do not show protection against a ground fault on the supply side of the main disconnect.

Sensing device and disconnect locations define zones of protection. Source side and ground return sensors provide protection only on the load side of associated disconnects. If a vector summation method is used and its sensors are located on load side of a disconnect, the zone between a source and actual sensor location becomes the responsibility of the next upstream protective device.

Table 17.2 Recommendations for Figures 18-23

<table>
<thead>
<tr>
<th>Ground Fault Protection</th>
<th>Figure</th>
<th>Sensing Method</th>
<th>Additional Ground Points</th>
<th>Recommended Use</th>
<th>Selectivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>On Main Disconnect Only</td>
<td>18</td>
<td>Vector Summation</td>
<td>Must not be downstream.</td>
<td>Minimum protection only per Section 230-95 for the National Electric Code</td>
<td>Limited selectivity depends on location of fault and rating of overcurrent devices on the upstream side of fault.</td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>Ground Return</td>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>On Main and Feeder Disconnects</td>
<td>20</td>
<td>Main and Feeder – Vector Summation</td>
<td>Must not be downstream of main ground fault sensor. May be upstream.</td>
<td>Improved service continuity is required</td>
<td>Main will allow feeder to trip for faults downstream of feeder sensors, but main will trip if feeder fails to operate.</td>
</tr>
<tr>
<td>On Main, Feeder, and Selected Branch Disconnects with Zone Selective Interlocking</td>
<td>21</td>
<td>Main – Ground Return Feeder – Vector Summation</td>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double-Ended System with Protection on Main and On Tie and FeederDisconnects</td>
<td>22</td>
<td>Main and Feeders 1-3 – Vector Summation MCC branch feeder A – Zero Sequence</td>
<td>Must not be downstream of main ground fault sensor. May be upstream.</td>
<td>Improved service continuity and minimum arcing fault damage are required and protection is needed on branch circuits.</td>
<td>Main and feeder 1-3 will provide delayed backup protection if fault is downstream of MCC branch feeder A. Main will provide delayed backup protection if fault is downstream of sensors for feeders 1-3. Main will trip on fastest curve if fault is upstream of sensors for feeders 1-3.</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>Main and Tie – Ground Return Feeder – Vector Summation</td>
<td>None</td>
<td></td>
<td>Double-ended systems with ground fault protection on tie disconnect where maximum continuity of service is essential.</td>
</tr>
</tbody>
</table>

Ground Fault Protection on Main Disconnects Only

![Figure 18](image)

![Figure 19](image)
Ground Fault Protection on Main and Feeder Disconnects

Ground Fault Protection on Main, Feeder and Selected Branch Disconnects with Zone Selective Interlocking

Double-Ended System with Ground Fault Protection on Main and on Tie and Feeder Disconnects

Note: Interlocking
Supplementary interlocking is required but will vary depending on equipment used.
**Ground Fault Protection**

**NEC Requirements for Ground Fault Protection**

**230.95 Ground-Fault Protection of Equipment.** Ground-fault protection of equipment shall be provided for solidly grounded wye electrical services of more than 150 volts to ground but not exceeding 600 volts phase-to-phase for each service disconnect rated 1000 amperes or more. The grounded conductor for the solidly grounded wye system shall be connected directly to ground without inserting any resistor or impedance device.

The rating of the service disconnect shall be considered to be the rating of the largest fuse that can be installed or the highest continuous current trip setting for which the actual overcurrent device installed in a circuit breaker is rated or can be adjusted.

Exception No. 1: The ground-fault protection provisions of this section shall not apply to a service disconnect for a continuous industrial process where a nonorderly shutdown will introduce additional or increased hazards.

Exception No. 2: The ground-fault protection provisions of this section shall not apply to fire pumps.

(A) Setting. The ground-fault protection system shall operate to cause the service disconnect to open all ungrounded conductors of the faulted circuit. The maximum setting of the ground-fault protection shall be 1200 amperes, and the maximum time delay shall be one second for ground-fault currents equal to or greater than 3000 amperes.

(B) Fuses. If a switch and fuse combination is used, the fuses employed shall be capable of interrupting any current higher than the interrupting capacity of the switch during a time that the ground-fault protective system will not cause the switch to open.

(C) Performance Testing. The ground-fault protection system shall be performance tested when first installed on site. The test shall be conducted in accordance with instructions that shall be provided with the equipment. A written record of this test shall be made and shall be available to the authority having jurisdiction.

(FPN No. 1): Ground-fault protection that functions to open the service disconnect affords no protection from faults on the line side of the protective element. It serves only to limit damage to conductors and equipment on the load side in the event of an arcing ground fault on the load side of the protective element.

(FPN No. 2): This added protective equipment at the service equipment may make it necessary to review the overall wiring system for proper selective overcurrent protection coordination. Additional installations of ground-fault protective equipment may be needed on feeders and branch circuits where maximum continuity of electrical service is necessary.

(FPN No. 3): Where ground-fault protection is provided for the service disconnect and interconnection is made with another supply system by a transfer device, means or devices may be needed to ensure proper ground-fault sensing by the ground-fault protection equipment.

(FPN No. 4): See 517.17(A) for information on where an additional step of ground fault protection is required for hospitals and other buildings with critical areas or life support equipment.

**517.17 Ground-Fault Protection.**

(A) Applicability. The requirements of 517.17 shall apply to hospitals and other buildings (including multiple occupancy buildings) with critical care areas or utilizing electrical life support equipment, and buildings that provide the required essential utilities or services for the operation of critical care areas or electrical life support equipment.

(B) Feeders. Where ground-fault protection is provided for operation of the service disconnecting means or feeder disconnecting means as specified by 230.95 or 215.10, an additional step of ground-fault protection shall be provided in all next level feeder disconnecting means downstream toward the load. Such protection shall consist of overcurrent devices and current transformers or other equivalent protective equipment that shall cause the feeder disconnecting means to open. The additional levels of ground-fault protection shall not be installed as follows:

(1) On the load side of an essential electrical system transfer switch

(2) Between the on-site generating unit(s) described in 517.35(B) and the essential electrical system transfer switch(es)

(3) On electrical systems that are not solidly grounded wye systems with greater than 150 volts to ground but not exceeding 600 volts phase-to-phase.

(C) Selectivity. Ground-fault protection for operation of the service and feeder disconnecting means shall be fully selective such that the feeder device, but not the service device, shall open on ground faults on the load side of the feeder device. A six-cycle minimum separation between the service and feeder ground-fault tripping bands shall be provided. Operating time of the disconnecting devices shall be considered in selecting the time spread between these two bands to achieve 100 percent selectivity.

(FPN): See 230.95, fine print note, for transfer of alternate source where ground-fault protection is applied.

(D) Testing. When equipment ground-fault protection is first installed, each level shall be performance tested to ensure compliance with 517.17(C).