

**Edison Electric Institute
Distributed Resources Task Force
Interconnection Study**

**By the
Interconnection Working Group**

**Murray Davis of Detroit Edison
Chair**

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The 29 EEI Distributed Resource System Protection and Coordination Issues

1. Improper Protective Device Coordination
Due to current contributions from Distributed Resources
Can change dramatically with DR “on “ and DR “off”
2. Nuisance Fuse Blowing
Due to current contribution from DR
Can turn temporary faults into permanent faults
3. Reclosing
Will reclose non-synchronous
Single Phase Devices are a problem
4. Installation of Transfer Trip Relaying
Trips all DR’s for temporary faults
Expensive & Who Pays?
5. Islanding
Safety Issue, DR maintains voltages after disconnection from utility source
6. Equipment Overvoltage
During faults, DR’s can force unfaulted phase voltage to 1.73 x nominal for
Delta-Delta transformations
7. Resonant Overvoltage
Can result when isolating synchronous generator with capacitors (Power Factor or
Line) during one line to ground faults
8. Harmonics
Inverters can inject harmonic Voltages/Currents into the utility grid.
9. Sectionalizers will not count w/o loss of voltage, therefore DR’s can cause sectionalizing
misoperations.
10. DR’s can cause reverse power relay malfunctions - also non-directional relay
malfunctions.
11. DR’s used to support voltage can cause a voltage regulation problem.
12. Voltage regulating devices such as line drop compensators are affected by DR
intervention. The current is reduced by the DR and the voltage at the feed point is
adjusted incorrectly, also voltage instability can occur.

13. Some LTC transformers with LDC are also affected by DR interaction.
14. Since all DR's are disconnected during a feeder outage, then when the feeder breaker is closed, the feeder loading capability could be exceeded (cold load pick-up problem).
15. Faults within a DR zone could cause interruption of feeder due to low DR impedance transformer.
16. Both a Problem/Solution - a recloser could provide a solution to isolate a DR and it's load for an upstream fault.
17. "Close - in "faults on other feeders fed from same bus can cause voltage dips on the remaining feeders, thus causing loss of DR on under voltage on these remaining feeders.
18. As additional DR units are added on a circuit, switchgear ratings (on existing DR units) could be exceeded.
19. Induction generators with capacitors can self excite under temporary or permanent isolated or islanding conditions.
20. DR's may encounter a problem of maintaining steady state stability on long feeders.
21. DR's may not maintain stability for faults on adjacent feeders fed from the same bus (during fault clearing period).
22. Loss of DR exciters will cause excessive reactive power losses and low voltages on a feeder. - static capacitors may be a requirement to solve this problem.
23. Current inrush on induction machines (w/o rotor flux) can cause voltage dips on a feeder.
24. Solution - voltages can be canceled by forced commutated inverters
25. Capacitor switching on a circuit may cause inverter trips or other voltage sensitive DR trips.
26. Voltage flicker (cyclic) can be produced due to down stream blades from wind generator towers; or due to intermittent cloud cover for PV's, or due to fluctuations in low quality fuel sources (Wind Utility Consulting Tom Wind ref. source)
27. Upstream single phase faults can cause fuse blowing due to "Y" connected (gd.) DR's
28. Under-frequency relaying with a wide tolerance band can cause DR's to trip while load remains - should be dropping the load first.

29. Distribution automation circuit reconfiguration schemes require extensive system protection coordination today, and must be studied for a number of normal and emergency state conditions. Remove control switches with intervening manual switches and hybrid three and five recloser loop schemes incorporating DR's may require additional DR protection and coordination.

Detailed Discussion of System Protection Used in Figure 1. Large Synchronous Generator (1-5 MVA) Connected to Wye Grounded Distribution Primary

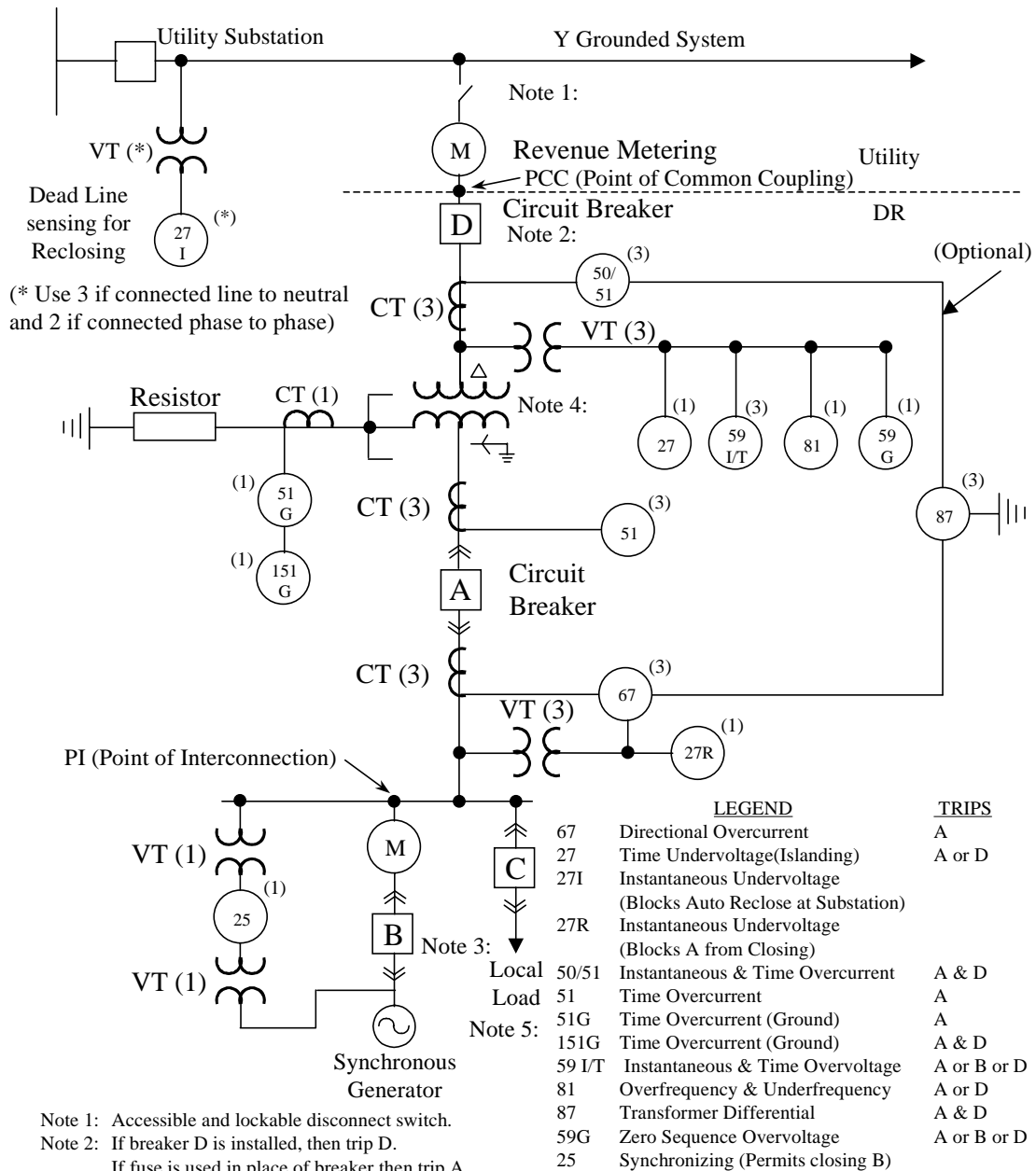


Figure 1. Large Synchronous Generator (1 - 5 MVA) connected to the Primary

Issues Addressed:

- **Reclosing out of Synchronism (3)**
- **Islanding (5)**
- **Equipment Overvoltage (6)**
- **Voltage Regulation Malfunction due to DR's (11)**
- **Cold Load Pick-up (14)**
- **Faults Within a DR Zone (15)**
- **Isolate DR for Upstream Fault (16)**
- **Fault Causes Voltage Dip – Trips DR (17)**
- **Loss of Exciter Causes Low Voltage (22)**
- **Inrush Of Induction Machines Causes Voltage Dips (23)**
- **Underfrequency (28)**

Protective Systems Required to Protect the Power System

The protection systems listed in this section are required to protect the utility power system from disturbances caused by DR's, or from operating the DR's under abnormal conditions.

1.1.1 Dead Line Sensing (27I) (Covers Issue #3)

When the utility substation breaker opens for a line fault, this breaker will reclose after the 27I drops out, showing the DR has been isolated and the line is dead, thereby the term dead line sensing has been used for this relay.

Substation breakers are normally not used to synchronize DR generators to the system. When the substation breaker is to be closed, the generation must be off-line. This includes automatic reclosing. There are a number of methods that can be used to isolate the DR from the utility system. See Item 1.1.6.

The dead line sensing scheme (27I) blocks reclosing of the substation circuit breaker if there is voltage present on the distribution circuit when the substation breaker is open. Consequently, the intent of this scheme is to avoid closing the substation breaker out of synchronism with the DR. Voltage transformers should be installed on the line side of the substation breaker to detect any source of backfeed on any phase conductor.

1.1.2 Phase Undervoltage Relaying (27) (Covers Issues #5, 11, 14, 17, 22, & 23)

This scheme is used to detect an abnormal low voltage at the point of common coupling with the utility system. Abnormal voltages could be the result of an islanding condition, or faults on the utility system. In an islanding condition, shutting down the generator will protect other utility customers within the island from continuing to receive voltage below ANSI C84.1.

A time delay (typically 2 seconds) is normally incorporated in this undervoltage detection system to allow for short term sags caused by utility system faults and faults behind breaker D in Figure 1. During a temporary period of cold load pickup, the time delay may have to be increased. This scheme must also allow for normal system voltage changes due to regulating devices and load changes.

1.1.3 Phase Overvoltage relaying (59I/T) (Covers Issues # 5, 6, & 11)

The 27 and 59 I/T relays detect out of limit voltage conditions and will cause disconnection of the DR when an islanding condition exists. The 59 I/T trips the DR for high voltage conditions. There are a number of methods that can be used to isolate the DR from the utility system. See Item 1.1.6.

It is possible for high voltage to occur in an island during light load condition. A malfunctioning AVR of the DR could also produce abnormally high voltage at the point of common coupling to the utility.

1.1.4 Under/Over Frequency (81) (Covers Issues #5, and 28)

The 81 relays detect out of limit frequency conditions and will cause the DR to be isolated from the islanded condition. The 81 relay causes the DR to become isolated for high or low frequency. There are a number of methods that can be used to isolate the DR from the utility system. See Item 1.1.6.

1.1.5 Zero Sequence Overvoltage (59G) (Covers Issues #5, 6, and 16)

This relay senses the overvoltage that results on the two unfaulted phases when a phase-to-ground fault occurs on a wye grounded utility system and the DR transformer primary is connected delta. The delta connection of the DR transformer primary prevents the transformer from contributing fault current. The overvoltage will continue unless the DR is isolated during this condition. There are a number of methods that can be used to isolate the DR from the utility system.

Note: If the transformer primary is connected grounded wye, the DR will contribute fault current to the faulted phase conductor and would be cleared by overcurrent relaying.

1.1.6 Breakers to be tripped by Undervoltage (27), Overvoltage (59I/T), Underfrequency (81) and Zero Sequence Overvoltage (59G) relays

Minimally, these relays must separate the utility's electric system from the DR. This can be done by tripping breaker A, B, or D, or any combination of these breakers. If it is possible and desirable to maintain generation service to the local load, tripping breaker A may be sufficient.

1.1.7 Transformer High Side Overcurrent Relays (50/51) (Covers Issues #15 and 16)

This system provides protection for transformer internal faults and faults within the zone between breaker A and the transformer. If transformer differential relays (87) are used, the 50/51 relays are strictly backup protection for faults within the DR system. The 50/51 relays may trip for faults on the utility system, if the DR generation can contribute sufficient fault current and generation overcurrent protection at breaker B is not coordinated with the 50/51 relays to trip first. Also see Item 1.1.13.

Other Protection Systems

The remaining protection systems, shown in Figure 1., are typically used to protect the DR from faults and facilitate operating the DR system. However, they are not required for interconnection.

1.1.8 Transformer Differential Relays (87) (Covers Issue #15)

These relays sense faults within their zone of protection, that is, between the transformer high side CTs and the CTs on breaker A. They provide high speed clearing for faults on the transformer and all of the bus within the protected zone. Depending on relay setting, they may or may not sense ground faults due to the limited current flowing through the ground resistor. These relays will normally trip breaker D and breaker A.

1.1.9 Transformer Neutral Ground Relays (51G), (151G) (Covers Issue #15)

The neutral ground (51G) relay senses ground faults on the secondary side of isolation transformer on the bus between breakers A, B, and C. The 51G relay causes breaker A to trip.

The relay designated 151G trips breakers A and D. This relay senses line to ground faults on the transformer secondary between the transformer and breaker A. When faults occur on the load side of breaker C, it is necessary to coordinate the time overcurrent relays on breaker C to prevent the 151G and 51G relays from tripping A or D.

1.1.10 Transformer Secondary Overcurrent Relays (51) (Covers Issue #15)

These three (3) relays clear phase to phase faults on the DR side of breaker A. They also can be used to backup downstream relays on breakers B and C for faults behind breakers B and C.

Note: Relays on breakers B and C are not shown.

These relays are set to coordinate with the 50/51 relays on the high side of the transformer. The 51 relays on breaker A will trip breaker A for faults on the DR side of breaker A before the 50/51 relays, on the transformer high side, trip breaker D.

1.1.11 Instantaneous Overvoltage to Prevent Closing (27R)

This relay blocks closing of breaker A if voltage is present on the bus between breakers A, B and C. The intent of this relay is to prevent an operator from closing breaker A when the DR is energized. Breaker A should only be closed when the bus between breakers A, B, and C is de-energized.

1.1.12 Synchronizing Relay (25)

This relay monitors the differences in voltages, frequency and phase angle on both sides of breaker B. If these differences are within specified limits, the relay permits closing of breaker B. If they are not within limits, it blocks closing of breaker B.

1.1.13 Directional Overcurrent (67) (Covers Issues #15, and 16)

To minimize the amount of load interrupted for faults between the DR transformer and breaker A, it may be desirable to use a directional overcurrent device to trip breaker A. The 50/51 device will trip breaker D.

The 67 device would be set to trip breaker A faster than the overcurrent relaying on breaker B would trip breaker B. Typically, a non-directional overcurrent (51) device on breaker A cannot be set to coordinate in this manner. The 67 device allows the DR to continue to serve local load. For faults on the utility system that are not isolated by other utility line protection, breaker A is also tripped by the 67 device. This also preserves the operation of the DR serving its local load.

Minimum System Protection Technical Requirements for Interconnection to the Utility

1.2.1 Out-of-Synchronism Reclosing Protection

The DR installation must include a protection system to isolate the DR from the utility system and communicate to the utility line breaker an open DR breaker status. Part of this system would include a dead line sensing system located at the utility substation breaker. By prior agreement with the utility, there could be a planned islanding condition, where the DR will continue to operate serving the islanded load with the substation line breaker blocked open.

1.2.2 Undervoltage Protection

The DR installation must have an undervoltage protection system to isolate the DR from the utility when the voltages at the point of common coupling are below the limits set by the utility for time in excess of that set by the utility (e.g. 85% of nominal for 2 minutes).

1.2.3* Overvoltage Protection

An overvoltage protection system must be installed to isolate the DR when the voltage and time limits have been exceeded. This system normally has an instantaneous trip value (e.g. 115% of nominal) and a time delay trip value (e.g. 110% for 2 minutes).

1.2.4* Under and Over Frequency Protection

A DR installation must be equipped with under/over frequency protection to trip the unit whenever the frequency is outside specified limits (e.g. ± 0.5 Hz).

1.2.5 Zero Sequence Overvoltage Protection

Zero sequence overvoltage protection is required to clear the DR unit for line to ground faults on a wye grounded utility system, where the DR transformer primary is delta connected.

1.2.6 Protection for Faults on the DR System

The DR system protection must incorporate the feature of isolating the DR from the utility system for faults on the DR system behind the point of common coupling (e.g. high side overcurrent sensing and trip system).

1.2.7 Transfer Trip Scheme NOT REQUIRED

***Note:** Whenever the minimum utility circuit load is three times larger than the aggregated DR capacity, then some utilities waive the need for over frequency and overvoltage protection requirements.

Other Requirements

1.3.1 Accessible Lockable Disconnect

An accessible lockable disconnect (See Note 1) must be provided at the point of common coupling to facilitate safe working conditions while maintaining the electric utility system.

1.3.2 Telemetry, Metering, Periodic Maintenance and Operating Agreements

Telemetry equipment, metering requirements, periodic maintenance requirements and operating agreements are other considerations that need to be addressed by the DR owner, the local customer and the utility. Suggested metering points are shown in this Figure as a circled letter M.

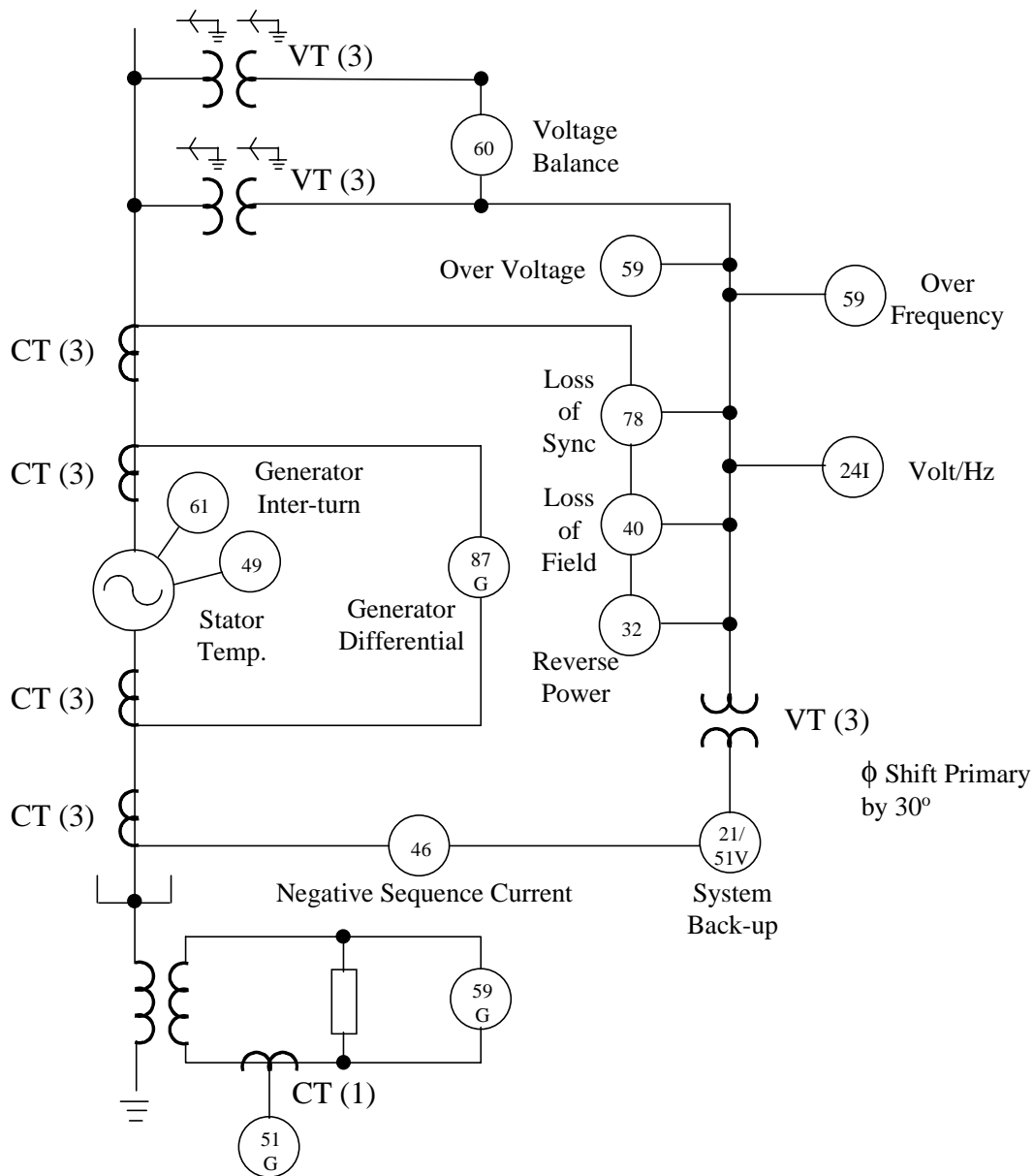


Figure 2. Typical Synchronous Generator Protection

Detailed Discussion of System Protection Used in Figure 3. Large Synchronous Generator (1-5 MVA) with Transfer Trip Relaying Connected to Wye Grounded Distribution Primary

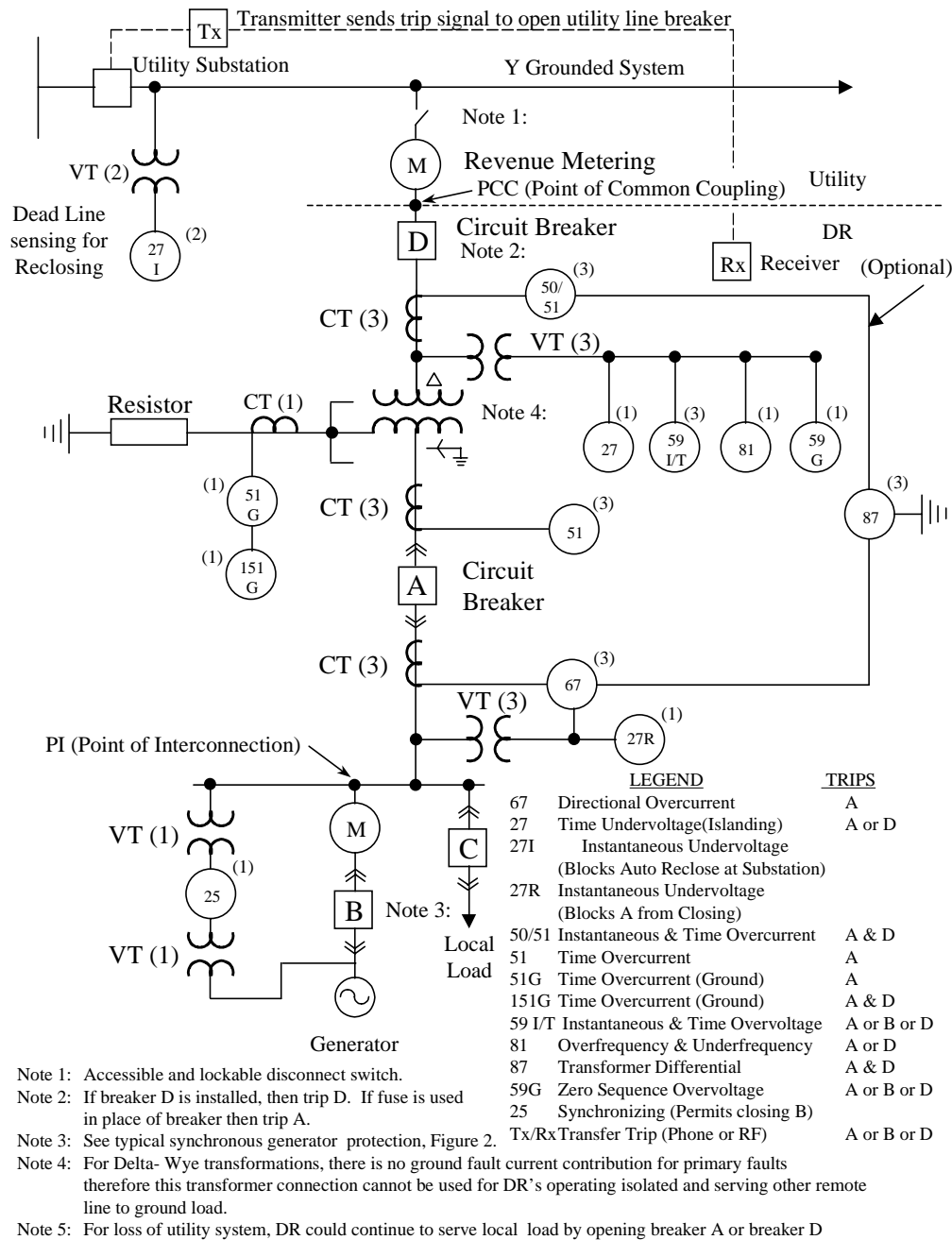


Figure 3. Large Synchronous Generator (1 - 5 MVA) with Transfer Trip Relaying

Issues Addressed:

- **Reclosing out of Synchronism (3)**
- **Transfer Tripping (4)**
- **Islanding (5)**
- **Equipment Overvoltage (6)**
- **Voltage Regulation Malfunction due to DR's (11)**
- **Cold Load Pick-up (14)**
- **Faults Within a DR Zone (15)**
- **Isolate DR for Upstream Fault (16)**
- **Fault Causes Voltage Dip – Trips DR (17)**
- **Loss of Exciter Causes Low Voltage (22)**
- **Inrush Of Induction Machines Causes Voltage Dips (23)**
- **Underfrequency (28)**

Protective Systems Required to Protect the Power System

The protection systems listed in this section are required to protect the utility power system from disturbances caused by DR's, or from operating the DR's under abnormal conditions. They are identical to the systems shown in Figure 1. with the exception of Transfer Trip Relaying. Please refer to the Detailed Discussion of System Protection for Figure 1. for System Protection shown in Figure 3.

See Items 1.1.1 through 1.1.7 of Figure 1.

3.1.1 Transfer Trip Relaying (Covers Issue #4)

For systems where DR's are not permitted to operate as an island, transfer tripping from the utility's breaker to the DR may be needed. The DR is automatically removed from the utility's system when the utility's breaker opens.

The Transmitter (Tx) is keyed to the audio tone trip frequency when the substation breaker is opened for any reason. Upon detection of the trip frequency, the receiver (Rx) closes contacts that will trip selected breakers to isolate the generation from the utility system.

Typically two audio frequencies are used. Under normal conditions, a guard frequency is transmitted from the transmitter to the receiver. As long as the receiver continues to receive the guard frequency from the transmitter, the receiver transmits a guard frequency back to the transmitter. If the transmitter fails to receive the guard frequency from the receiver, an alarm is generated. By this re-transmitting of the guard frequency by the receiver, the integrity of the communication channel is monitored.

Other Protection Systems

The remaining protection systems, shown in Figure 3., are typically used to protect the DR from faults and facilitate operating the DR system. However, they are not required for interconnection. They are similar to the schemes shown in Figure 1.

Minimum System Protection Technical Requirements for Interconnection to the Utility

3.2.1 Out-of-Synchronism Reclosing Protection

See Item 1.2.1.

3.2.2 Undervoltage Protection

See Item 1.2.2.

3.2.3* Overvoltage Protection

See Item 1.2.3.

3.2.4* Under and Over Frequency Protection

See Item 1.2.4.

3.2.5 Zero Sequence Overvoltage Protection

See Item 1.2.5.

3.2.6 Protection for Faults on the DR System

See Item 1.2.6.

3.2.7 Transfer Trip Scheme

Whenever the aggregated generation capacity exceeds the minimum utility circuit load, the utility may require a transfer trip scheme to isolate the DR from the utility system when the substation breaker is open. See Figure 3. There may be cases when the DR can serve an islanded load as in Figure 1., if arrangements have been agreed to by the utility and the DR owner.

***Note:** Whenever the minimum utility circuit load is three times larger than the aggregated DR capacity, then some utilities waive the need for over frequency and overvoltage protection requirements.

Other Requirements

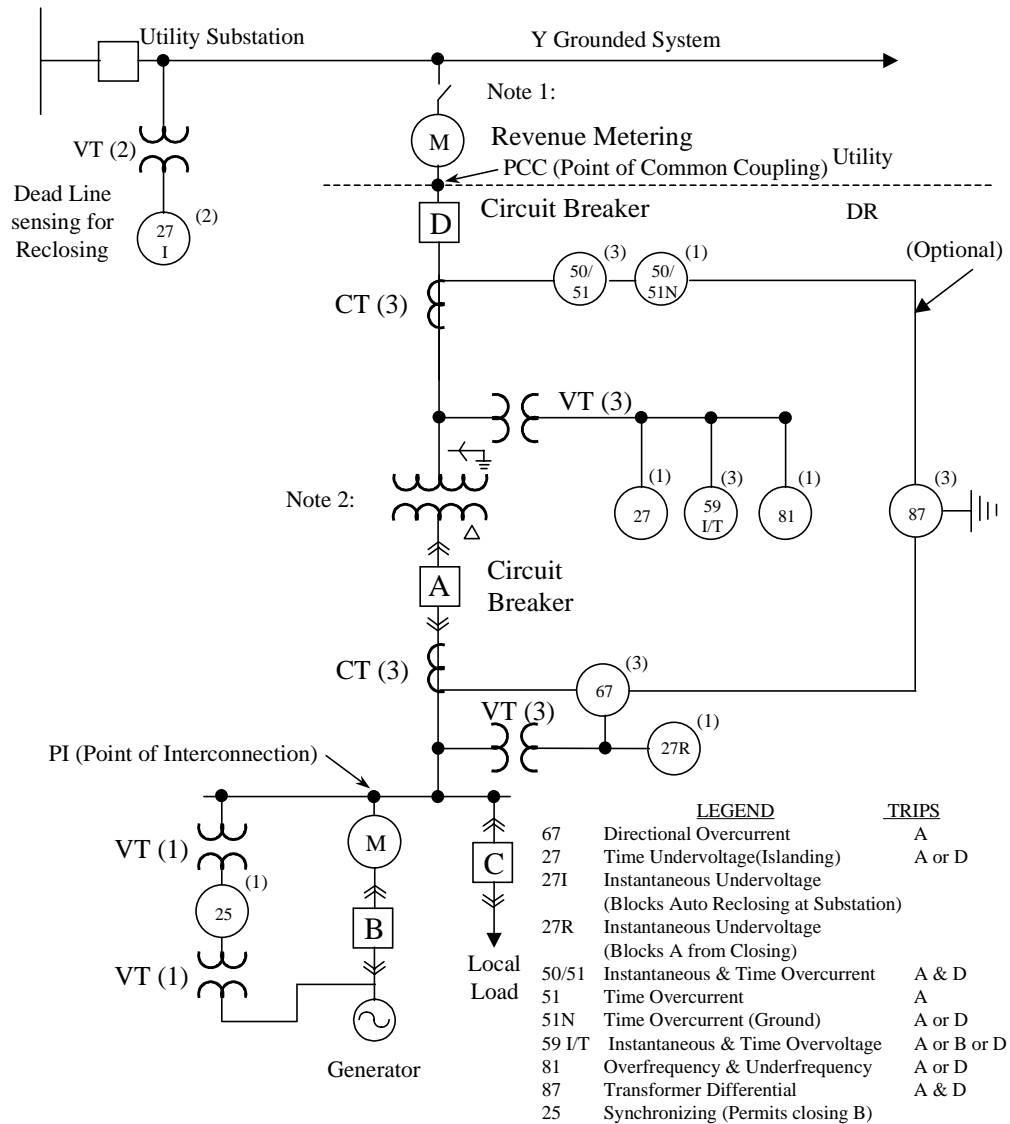
3.3.1 Accessible Lockable Disconnect

See Item 1.3.1.

3.3.2 Telemetry, Metering, Periodic Maintenance and Operating Agreements

See Item 1.3.2.

Detailed Discussion of System Protection Used in Figure 4. Large Synchronous Generator (1-5 MVA) Connected to the Primary and Serving Other Remote Isolated Loads



Note 1: Accessible and lockable disconnect switch.

Note 2: DR's using Wye-Delta transformations can run isolated and serve other remote loads.

Note 3: For loss of utility system, DR could continue to serve local load by opening breaker A or breaker D

Figure 4. Large Synchronous Generator (1 - 5 MVA) connected to the Primary and serving other isolated remote loads.

Issues Addressed:

- **Reclosing out of Synchronism (3)**
- **Islanding (5)**
- **Equipment Overvoltage (6)**
- **Voltage Regulation Malfunction due to DR's (11)**
- **Cold Load Pick-up (14)**
- **Faults Within a DR Zone (15)**
- **Isolate DR for Upstream Fault (16)**
- **Fault Causes Voltage Dip – Trips DR (17)**
- **Loss of Exciter Causes Low Voltage (22)**
- **Inrush Of Induction Machines Causes Voltage Dips (23)**
- **Underfrequency (28)**

Protective Systems Required to Protect the Power System

The protection systems listed in this section are required to protect the utility power system from disturbances caused by DR's, or from operating the DR's under abnormal conditions. This Figure differs from Figures 1. and 3. in that the transformer is connected grounded wye – delta. The grounded wye primary permits the DR to serve load connected line-to-ground, while being isolated from the utility source.

This configuration has some issues worth reviewing. The grounded wye-delta transformer configuration becomes a ground current source. Coordination studies must take this into account. At present, some utilities will not ordinarily permit this connection, because of the “desensitizing” effect this ground source has on other ground relays at the substation.

Also, note that this configuration does not have a 59G relay. It is not needed in this case, because the DR will be contributing current to any line-to-ground fault on the utility system. The DR in Figure 1. does not contribute ground fault current and requires the 59G relay to prevent sustained overvoltage after separation from the utility source.

4.1.1 Dead Line Sensing (27I) (Covers Issue #3)

See Item 1.1.1.

4.1.2 Phase Undervoltage Relaying (27) (Covers Issues #5, 11, 14, 17, 22, & 23)

See Item 1.1.2.

4.1.3 Phase Overvoltage relaying(59I/T) (Covers Issues # 5, 6 & 11)

See Item 1.1.3.

4.1.4 Under/Over Frequency (81) (Covers Issues #5, and 28)

See Item 1.1.4.

4.1.5 Zero Sequence Overvoltage (59G) (Covers Issues #5, 6, and 16) (NOT REQUIRED for this Figure)

This scheme is not required due to wye connected primary of transformer.

4.1.6 Breakers to be tripped by Undervoltage (27), Overvoltage (59I/T), Underfrequency (81) relays

See Item 1.1.6.

4.1.7 Transformer High Side Overcurrent Relays 50/51, 50/51N (Covers Issues #15 and 16)

This system provides protection for transformer internal faults and faults within the zone between breaker A and the transformer. If transformer differential relays (87) are used, the 50/51 relays are strictly backup protection for faults within the DR system. The 50/51 and/or 50/51N relays may trip for faults on the utility system, if the DR generation can contribute sufficient fault current and generation overcurrent protection at breaker B is not coordinated with the 50/51 relays to trip first. Also see Item 1.1.13.

Other Protection Systems

The remaining protection systems, shown in Figure 4., are typically used to protect the DR from faults and facilitate operating the DR system. However, they are not required for interconnection.

4.1.8 Transformer Differential Relays (87) (Covers Issue #15)

These relays sense faults within their zone of protection, that is, between the transformer high side CTs and the CTs on breaker A. They provide high speed clearing for faults on the transformer and all of the bus within the protected zone. These relays will normally trip breaker D and breaker A.

4.1.9 Transformer Neutral Ground Relays (51G), (151G) (NOT REQUIRED)

These relays are not needed due to the ungrounded delta configuration of the transformer.

4.1.10 Transformer Secondary Overcurrent Relays (51) (Covers Issue #15)

These relays are not shown. Refer to Figure 1. for typical connection.

See Item 1.1.10 for operation.

4.1.11 Instantaneous Overvoltage to Prevent Closing (27R)

See Item 1.1.11.

4.1.12 Synchronizing Relay (25)

See Item 1.1.12.

4.1.13 Directional Overcurrent (67) (Covers Issues #15, and 16)

See Item 1.1.13.

Minimum System Protection Technical Requirements for Interconnection to the Utility

4.2.1 Out-of-Synchronism Reclosing Protection

See Item 1.2.1.

4.2.2 Undervoltage Protection

See Item 1.2.2.

4.2.3* Overvoltage Protection

See Item 1.2.3.

4.2.4* Under and Over Frequency Protection

See Item 1.2.4.

4.2.5 Zero Sequence Overvoltage is NOT REQUIRED

4.2.6 Protection for Faults on the DR System

See Item 1.2.6.

4.2.7 Transfer Trip Scheme NOT REQUIRED

***Note:** Whenever the minimum utility circuit load is three times larger than the aggregated DR capacity, then some utilities waive the need for over frequency and overvoltage protection requirements.

Other Requirements

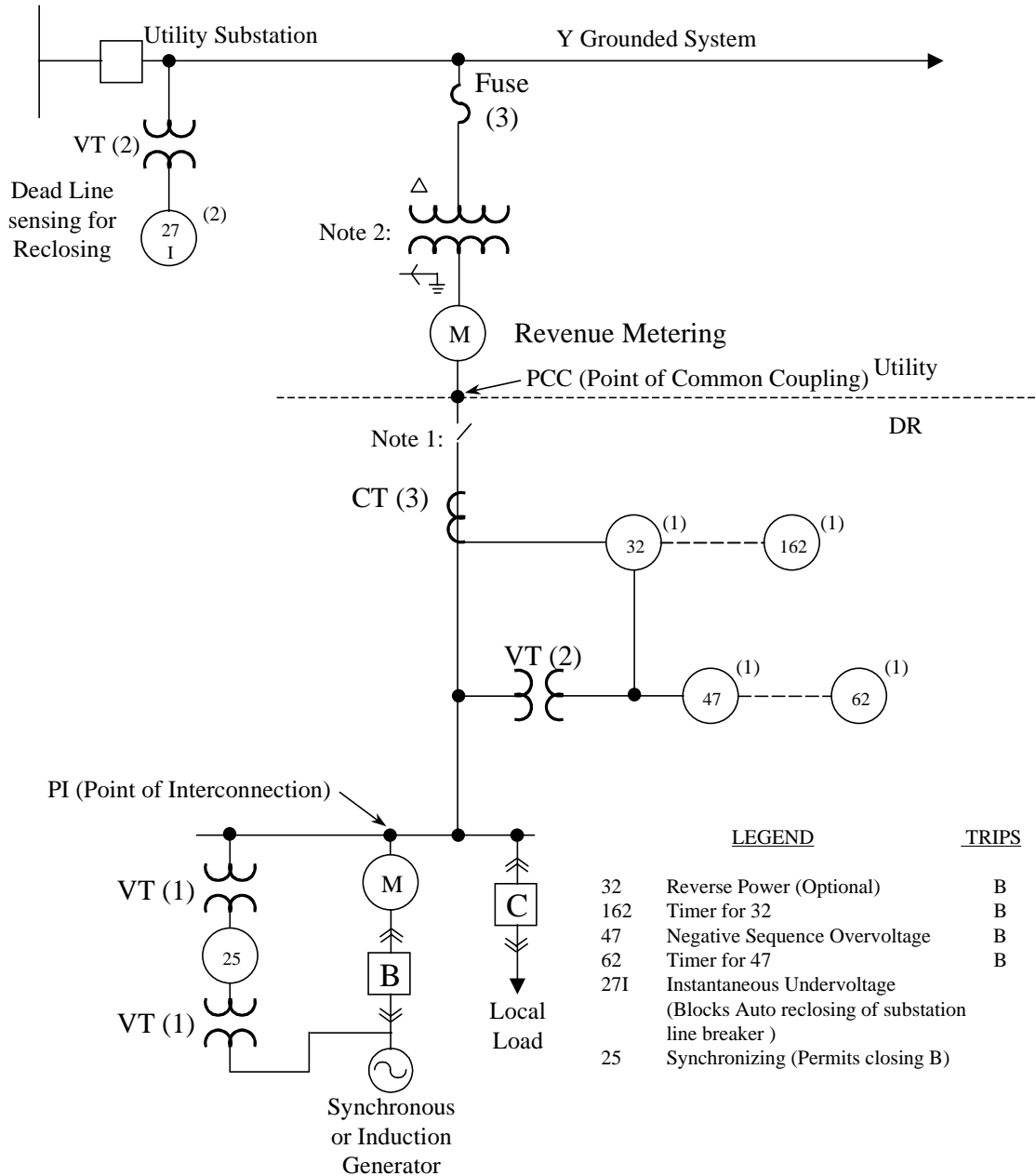
4.3.1 Accessible Lockable Disconnect

See Item 1.3.1.

4.3.2 Telemetry, Metering, Periodic Maintenance and Operating Agreements

See Item 1.3.2.

Figure 5. Small Synchronous or Induction Generator (10-100kVA) Connected to the Primary



Note 1: Alternate Location for Accessible and lockable disconnect switch.

Note 2: For Delta- Wye transformations, there is no ground fault current contribution for primary faults therefore this transformer connection cannot be used for DR's operating isolated and serving other remote line to ground loads.

Note 3: The synchronizing relay 25 is needed for the synchronous generator only.

Figure 5. Small Synchronous (≤ 100 kVA) or Induction (≤ 100 kVA) Three-Phase Generator connected to Primary

Issues Addressed:

- **Reclosing out of Synchronism (3)**
- **Islanding (5)**
- **Faults Within a DR Zone (15)**
- **Isolate DR for Upstream Fault (16)**

Protective Systems Required to Protect the Power System

The protection systems listed in this section are required to protect the utility power system from disturbances caused by DR's, or from operating the DR's under abnormal conditions. Because this is a relatively small DR, and will have minimal effect on the operation of the utility system, a simplified protection system is employed. A reverse power relay is used to prevent power flow from the DR to the utility system.

5.1.1 Dead Line Sensing (27I) (Covers Issue #3)

This would normally not be required for a DR of this size. The DR would be expected to be off-line prior to any time delayed reclosing operation. If an immediate reclosing is utilized, then dead line sensing might be considered. Even then it is unlikely the DR will be capable of sustaining a voltage detectable at the substation when isolated from the utility, because of its relatively small size compared to the circuit load.

5.1.2 Phase Undervoltage Relaying (27) NOT REQUIRED

5.1.3 Phase Overvoltage relaying(59I/T) Not Required

5.1.4 Under/Over Frequency (81) Not Required

5.1.5 Zero Sequence Overvoltage (59G) Not Required

5.1.6 Reverse Power Relay (32) (Covers Issue #5)

This device senses powerflow to the utility system and causes breaker B to trip. A timing relay is utilized to override the transient powerflow that occurs during system faults that are successfully isolated by other devices on the utility system.

5.1.7 Breakers to be tripped by 32 relay

Breaker B is required to be tripped by the 32 relay, since this is the only electrically operated device that can isolate the DR from the utility system.

5.1.8 Primary Fuses or Transformer High Side Overcurrent Relays 50/51, 50/51N (Covers Issues #15 and 16)

The primary fuses will isolate faults beyond the point of common coupling. They should also be selected to coordinate with utility system protective devices and downstream DR devices.

Other Protection Systems

The remaining protection systems, shown in Figure 5., are typically used to protect the DR from faults and facilitate operating the DR system. However, they are not required for interconnection.

5.1.9 Transformer Differential Relays (87) Not Applicable

5.1.10 Transformer Neutral Ground Relays (51G), (151G) Not Applicable

5.1.11 Transformer Secondary Overcurrent Relays (51) Not Applicable

5.1.12 Instantaneous Overvoltage to Prevent Closing (27R) Not Applicable

5.1.13 Synchronizing Relay (25)

See Item 1.1.12.

5.1.14 Negative Sequence Overvoltage (47)

This relay can detect blown fuses or dead phases on the primary of the transformer. It would be normally connected to trip breaker B. It may also be prudent to trip breaker C to protect the load from the sometimes damaging effects of single phasing.

Minimum System Protection Technical Requirements for Interconnection to the Utility

5.2.1 Reverse Power Protection

See Item 5.1.6.

5.2.2 Undervoltage Protection NOT REQUIRED

5.2.3 Overvoltage Protection NOT REQUIRED

5.2.4 Under and Over Frequency Protection NOT REQUIRED

5.2.5 Zero Sequence Overvoltage NOT REQUIRED

5.2.6 Protection for Faults on the DR System

Fuses provide the necessary isolation for faults beyond the point of common coupling to the DR.

5.2.7 Transfer Trip Scheme NOT REQUIRED

Other Requirements

5.3.1 Accessible Lockable Disconnect

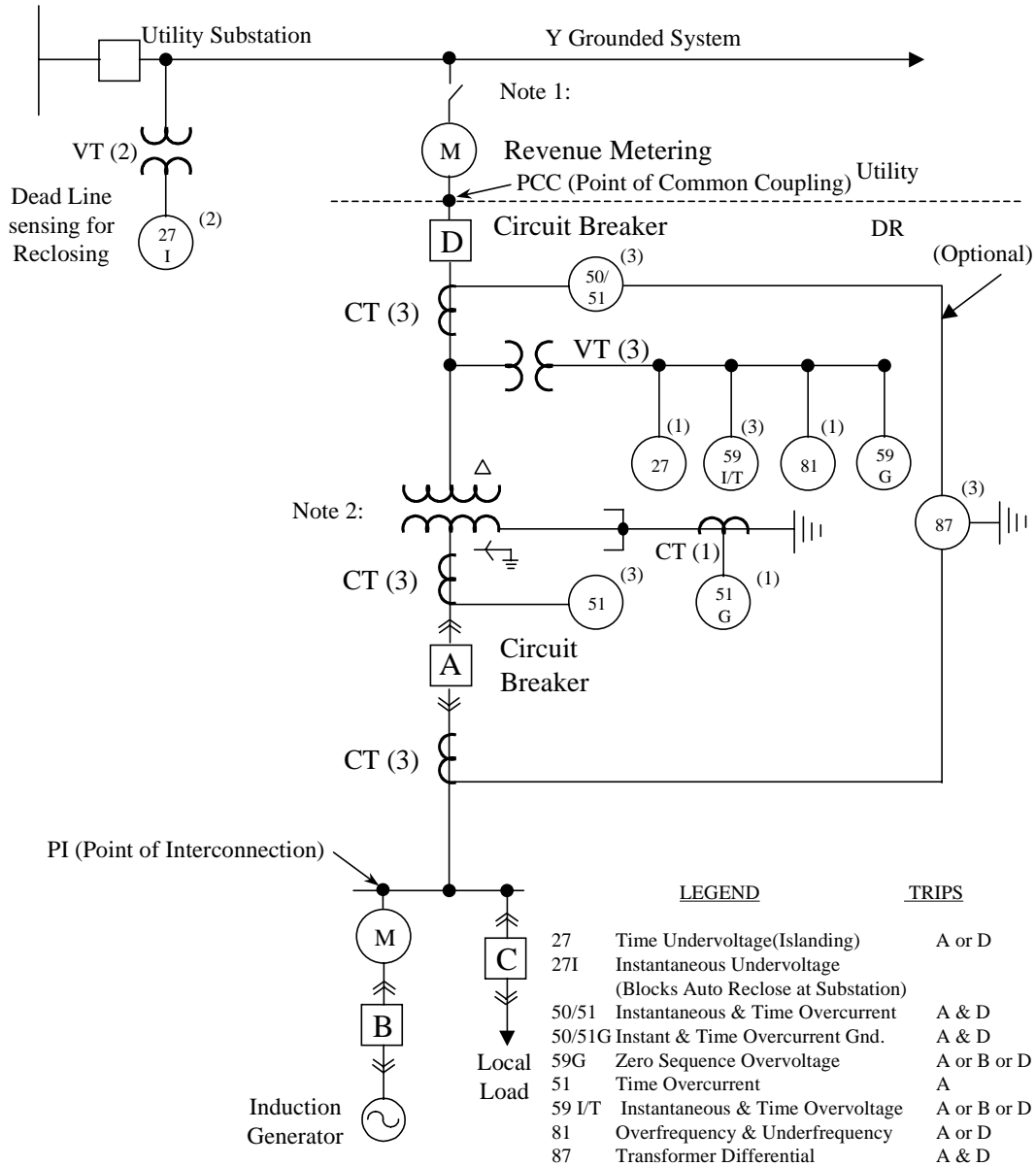
See Item 1.3.1.

5.3.2 Telemetry, Metering, Periodic Maintenance and Operating Agreements

Telemetry would normally not be done for such a small DR. However, local circumstances may dictate that some form of telemetry be installed.

See Item 1.3.2.

Detailed Discussion of System Protection Used in Figure 6. Large Induction Generator (1-5 MVA) Connected to the Primary



Note 1: Accessible and lockable disconnect switch.

Note 2: For Delta- Wye transformations, there is no ground fault current contribution for primary faults, therefore this transformer connection cannot be used for DR's operating isolated and serving other remote line to ground load.

Note 3: For loss of utility system, DR could continue to serve local load by opening breaker A or breaker D. This assumes power factor correction capacitors provide enough reactive.

Figure 6. Large Induction Generator (1 - 5 MVA) connected to the Primary

Issues Addressed:

- **Reclosing out of Synchronism (3)**
- **Islanding (5)**
- **Equipment Overvoltage (6)**
- **Voltage Regulation Malfunction due to DR's (11)**
- **Cold Load Pick-up (14)**
- **Faults Within a DR Zone (15)**
- **Isolate DR for Upstream Fault (16)**
- **Fault Causes Voltage Dip – Trips DR (17)**
- **Loss of Exciter Causes Low Voltage (22)**
- **Inrush Of Induction Machines Causes Voltage Dips (23)**
- **Underfrequency (28)**

Protective Systems Required to Protect the Power System

Figure 6. consists of a large induction generator connected to the primary, similar to the synchronous generator shown in Figure 1. The minimal technical requirements for interconnection are similar. The transformer is however shown as being solidly grounded.

The protection systems listed in this section are required to protect the utility power system from disturbances caused by DR's, or from operating the DR's under abnormal conditions.

6.1.1 Dead Line Sensing (27I) (Covers Issue #3)

Some utilities may not require this since an induction generator will typically lose excitation quickly after loss of the source voltage.

See Item 1.1.1.

6.1.2 Phase Undervoltage Relaying (27) (Covers Issues #5, 11, 14, 17, 22, & 23)

See Item 1.1.2.

6.1.3 Phase Overvoltage relaying(59I/T) (Covers Issues # 5, 6 & 11)

See Item 1.1.3.

6.1.4 Under/Over Frequency (81) (Covers Issues #5, and 28)

See Item 1.1.4.

6.1.5 Zero Sequence Overvoltage (59G) (Covers Issues #5, 6, and 16)

See Item 1.1.5.

6.1.6 Breakers to be tripped by 27, 59I/T, 81, and 59G relays

See Item 1.1.6.

6.1.7 Transformer High Side Overcurrent Relays (50/51) (Covers Issues #15 and 16)

See Item 1.1.7.

Other Protection Systems

The remaining protection systems, shown in Figure 6., are typically used to protect the DR from faults and facilitate operating the DR system. However, they are not required for interconnection.

6.1.8 Transformer Differential Relays (87) (Covers Issue #15)

See Item 1.1.8.

6.1.9 Transformer Neutral Ground Relay (51G), (Covers Issue #15)

See Item 1.1.9.

Note this system is only using one relay (51G). The designer may choose to add an additional ground relay to the transformer neutral CT, or to breaker A to provide additional selectivity and reliability.

6.1.10 Transformer Secondary Overcurrent Relays (51) (Covers Issue #15)

See Item 1.1.10.

6.1.11 Instantaneous Overvoltage to Prevent Closing (27R)

Not normally required for an induction generator since synchronizing is not needed when closing breaker A. See Item 1.1.11 for comparison to synchronous generator.

6.1.12 Synchronizing Relay (25)

Not required for an induction generator. See Item 1.1.12 for comparison to synchronous generator.

Minimum System Protection Technical Requirements for Interconnection to the Utility

6.2.1 Out-of-Synchronism Reclosing Protection

See Item 1.2.1.

6.2.2 Undervoltage Protection

See Item 1.2.2.

6.2.3* Overvoltage Protection

See Item 1.2.3.

6.2.4* Under and Over Frequency Protection

See Item 1.2.4.

6.2.5 Zero Sequence Overvoltage Protection

See Item 1.2.5.

6.2.6 Protection for Faults on the DR System

See Item 1.2.6.

6.2.7 Transfer Trip Scheme NOT REQUIRED

***Note:** Whenever the minimum utility circuit load is three times larger than the aggregated DR capacity, then some utilities waive the need for over frequency and overvoltage protection requirements.

Other Requirements

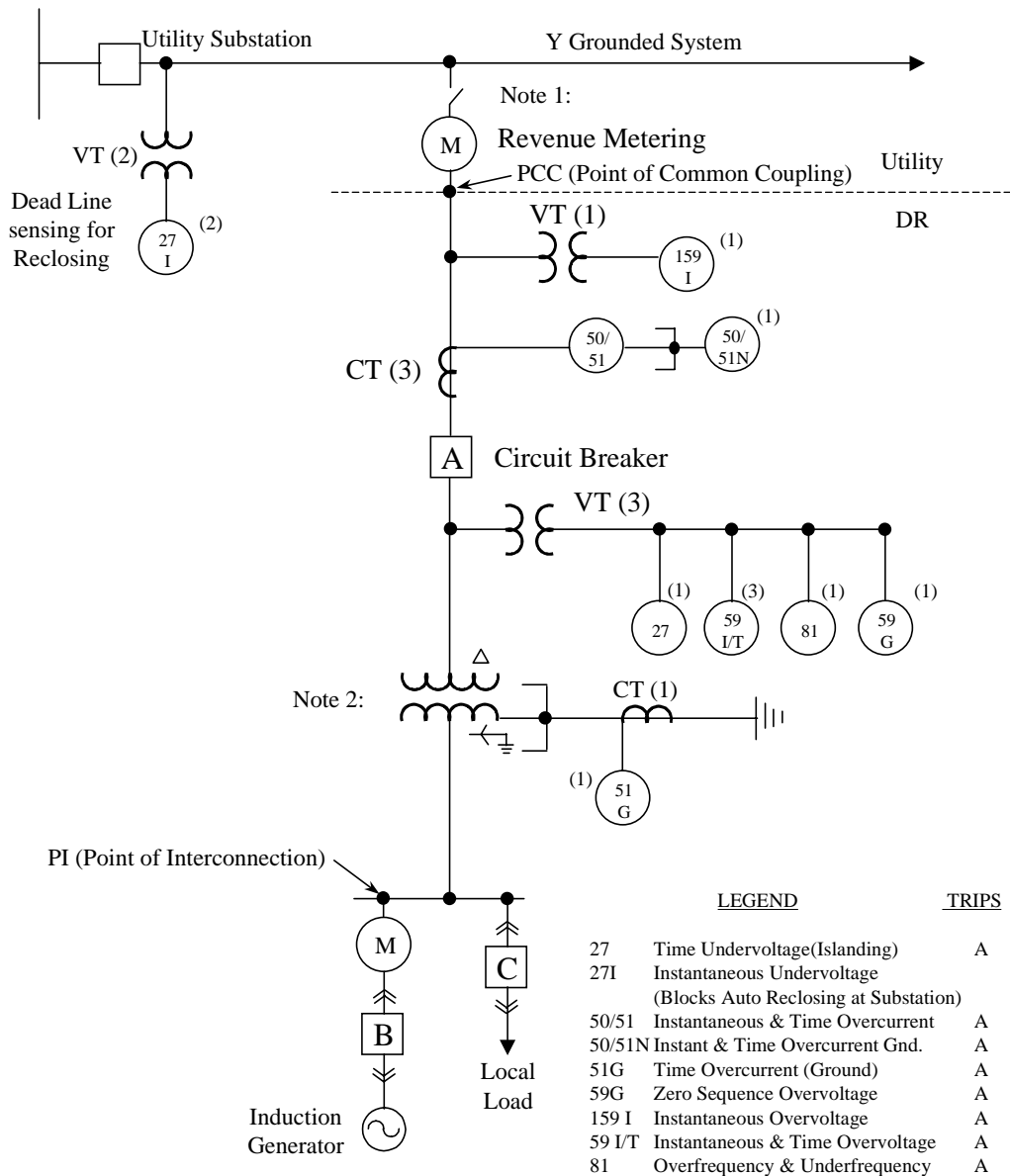
6.3.1 Accessible Lockable Disconnect

See Item 1.3.1.

6.3.2 Telemetry, Metering, Periodic Maintenance and Operating Agreements

See Item 1.3.2.

Detailed Discussion of System Protection Used in Figure 7. Large Induction Generator (1-5 MVA) Connected to the Primary with High Side Breaker Only



Note 1: Accessible and lockable disconnect switch.

Note 2: For Delta- Wye transformations, there is no ground fault current contribution for primary faults, therefore this transformer connection cannot be used for DR's operating isolated and serving other remote line to ground load.

Note 3: For loss of utility system, DR could continue to serve local load by opening breaker A.

Figure 7. Large Induction Generator (1 - 5 MVA) with High - Side Breaker (only)

Issues Addressed:

- **Reclosing out of Synchronism (3)**
- **Islanding (5)**
- **Equipment Overvoltage (6)**
- **Voltage Regulation Malfunction due to DR's (11)**
- **Cold Load Pick-up (14)**
- **Faults Within a DR Zone (15)**
- **Isolate DR for Upstream Fault (16)**
- **Fault Causes Voltage Dip – Trips DR (17)**
- **Loss of Exciter Causes Low Voltage (22)**
- **Inrush Of Induction Machines Causes Voltage Dips (23)**
- **Underfrequency (28)**

Protective Systems Required to Protect the Power System

Figure 7. consists of a large induction generator connected to the primary, similar to the synchronous generator shown in Figure 1. The minimal technical requirements for interconnection are similar. The transformer is however shown as being solidly grounded.

The protection systems listed in this section are required to protect the utility power system from disturbances caused by DR's, or from operating the DR's under abnormal conditions.

7.1.1 Dead Line Sensing (27I) (Covers Issue #3)

Some utilities may not require this since an induction generator will typically lose excitation quickly after loss of the source voltage.

See Item 1.1.1.

7.1.2 Phase Undervoltage Relaying (27) (Covers Issues #5, 11, 14, 17, 22, & 23)

See Item 1.1.2.

7.1.3 Phase Overvoltage relaying(59I/T) (Covers Issues # 5, 6, & 11)

See Item 1.1.3.

7.1.4 Under/Over Frequency (81) (Covers Issues #5, and 28)

See Item 1.1.4.

7.1.5 Zero Sequence Overvoltage (59G) (Covers Issues #5, 6, and 16)

See Item 1.1.5.

7.1.6 Breakers to be tripped by 27, 59I/T, 81, and 59G relays

Minimally these relays must separate the utility's electrical system from the DR. This can be done by tripping breaker A, or B. If it is possible and desirable to maintain generation service to the local load, tripping breaker A may be sufficient.

7.1.7 Transformer High Side Overcurrent Relays (50/51)(50/51N) (Covers Issues #15 and 16)

See Item 1.1.7. This scheme also includes a neutral relay (50/51N). It senses line-to-ground faults on the high side of the transformer. This neutral relay can normally be set more sensitive than the phase relays and does not have to be coordinated with relays on the secondary of the transformer, because no zero sequence current flows on the high side for secondary faults.

Other Protection Systems

The remaining protection systems, shown in Figure 7., are typically used to protect the DR from faults and facilitate operating the DR system. However, they are not required for interconnection.

7.1.8 Transformer Differential Relays (87) (Covers Issue #15) Not Applicable

7.1.9 Transformer Neutral Ground Relays (51G) (Covers Issue #15)

See Item 1.1.9.

Note this system is only using one relay (51G).

7.1.10 Transformer Secondary Overcurrent Relays (51) Not Applicable

7.1.11 Instantaneous Overvoltage to Prevent Closing (159I)

Not normally required for an induction generator since synchronizing is not needed when closing breaker A. See Item 1.1.11 for comparison to synchronous generator.

7.1.12 Synchronizing Relay (25)

Not required for an induction generator. See Item 1.1.12 for comparison to synchronous generator.

Minimum System Protection Technical Requirements for Interconnection to the Utility

7.2.1 Out-of-Synchronism Reclosing Protection

See Item 1.2.1.

7.2.2 Undervoltage Protection

See Item 1.2.2.

7.2.3* Overvoltage Protection

See Item 1.2.3.

7.2.4* Under and Over Frequency Protection

See Item 1.2.4.

7.2.5 Zero Sequence Overvoltage Protection

See Item 1.2.5.

7.2.6 Protection for Faults on the DR System

See Item 1.2.6.

7.2.7 Transfer Trip Scheme NOT REQUIRED

***Note:** Whenever the minimum utility circuit load is three times larger than the aggregated DR capacity, then some utilities waive the need for over frequency and overvoltage protection requirements.

Other Requirements

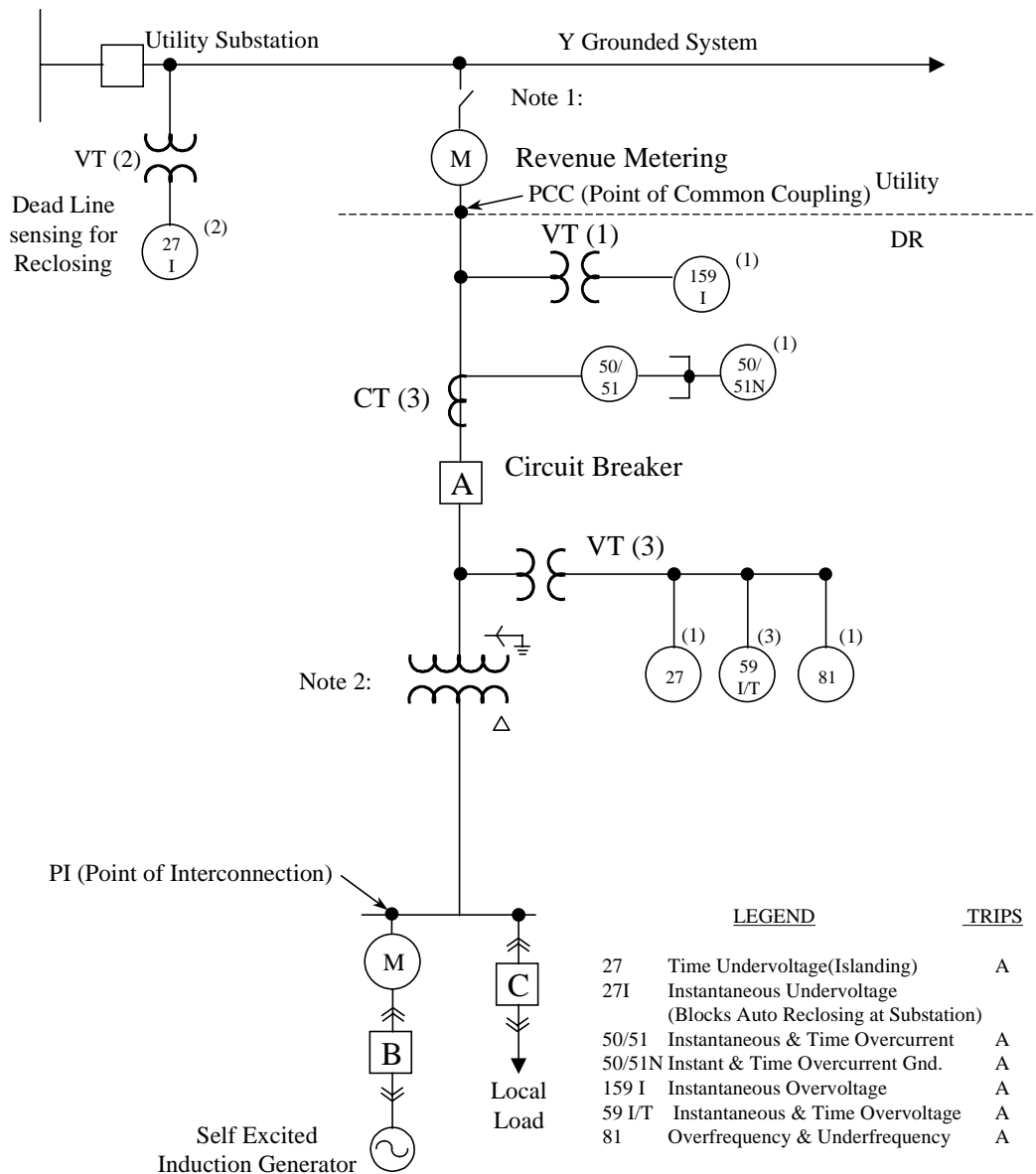
7.3.1 Accessible Lockable Disconnect

See Item 1.3.1.

7.3.2 Telemetry, Metering, Periodic Maintenance and Operating Agreements

See Item 1.3.2.

Detailed Discussion of System Protection Used in Figure 8. Large Self Excited Induction Generator (1-5 MVA) Connected to the Primary Serving other Isolated Loads



Note 1: Accessible and lockable disconnect switch.

Note 2: DR's using Wye-Delta transformations can run isolated and serve other remote loads.

Note 3: For loss of utility system, DR could continue to serve local load by opening breaker A.

Figure 8. Large Self Excited Induction Generator (1 - 5 MVA) with High-Side Breaker only and connected to the Primary serving other isolated remote loads.

Issues Addressed:

- **Reclosing out of Synchronism (3)**
- **Islanding (5)**
- **Equipment Overvoltage (6)**
- **Voltage Regulation Malfunction due to DR's (11)**
- **Cold Load Pick-up (14)**
- **Faults Within a DR Zone (15)**
- **Isolate DR for Upstream Fault (16)**
- **Fault Causes Voltage Dip – Trips DR (17)**
- **Loss of Exciter Causes Low Voltage (22)**
- **Inrush Of Induction Machines Causes Voltage Dips (23)**
- **Underfrequency (28)**

Protective Systems Required to Protect the Power System

Figure 8. consists of a large, self excited, induction generator connected to the primary, similar to the synchronous generator shown in Figure 4. The minimal technical requirements for interconnection are similar to the synchronous generator shown in Figure 4. The transformer is shown as being solidly grounded on the primary.

Sufficient reactive support is assumed to be available to permit the induction generator to operate isolated from the utility source and maintain adequate voltage and frequency. Technical issues related to maintaining voltage and frequency with an isolated induction generator are discussed in the issues section of this document.

The protection systems listed in this section are required to protect the utility power system from disturbances caused by DR's, or from operating the DR's under abnormal conditions.

8.1.1 Dead Line Sensing (27I) (Covers Issue #3)

See Item 1.1.1.

8.1.2 Phase Undervoltage Relaying (27) (Covers Issues #5, 11, 14, 17, 22, & 23)

See Item 1.1.2.

8.1.3 Phase Overvoltage relaying(59I/T) (Covers Issues # 5, 6 & 11)

See Item 1.1.3.

8.1.4 Under/Over Frequency (81) (Covers Issues #5, and 28)

See Item 1.1.4.

8.1.5 Zero Sequence Overvoltage (59G) NOT REQUIRED

8.1.6 Breakers to be tripped by Undervoltage (27), Overvoltage (59I/T), Underfrequency (81) relays

Minimally these relays must separate the utility's electrical system from the DR. This can be done by tripping breaker A, or B. If it is possible and desirable to maintain generation service to the local load, tripping breaker A may be sufficient.

8.1.7 Transformer High Side Overcurrent Relays (50/51)(50/51N) (Covers Issues #15 and 16)

See Item 1.1.7. This scheme also includes a neutral relay (50/51N). It senses line-to-ground faults on the high side of the transformer. Because the transformer will contribute current to line-to-ground faults on the utility system, consideration must be given to how the neutral relay is to be coordinated with other devices on the utility system. The 50/51N relay should be coordinated with other devices on the utility system to permit them to clear most line to ground faults on the utility system before the 50/51N relay operates.

Other Protection Systems

The remaining protection systems, shown in Figure 8., are typically used to protect the DR from faults and facilitate operating the DR system. However, they are not required for interconnection.

8.1.8 Transformer Differential Relays (87) (Covers Issue #15) Not Applicable

8.1.9 Transformer Neutral Ground Relays (51G), (151G) Not Applicable

8.1.10 Transformer Secondary Overcurrent Relays (51) Not Applicable

8.1.11 Instantaneous Overvoltage to Prevent Closing (159I)

Because this generator is self excited, this relay may be desirable to prevent closing of breaker A out of synchronism with the generator. See Item 1.1.11 for comparison to synchronous generator.

8.1.12 Synchronizing Relay (25)

Not required for an induction generator. See Item 1.1.12 for comparison to synchronous generator.

Minimum System Protection Technical Requirements for Interconnection to the Utility

8.2.1 Out-of-Synchronism Reclosing Protection

See Item 1.2.1.

8.2.2 Undervoltage Protection

See Item 1.2.2.

8.2.3* Overvoltage Protection

See Item 1.2.3.

8.2.4* Under and Over Frequency Protection

See Item 1.2.4.

8.2.5 Zero Sequence Overvoltage Protection NOT REQUIRED

8.2.6 Protection for Faults on the DR System

See Item 1.2.6.

8.2.7 Transfer Trip Scheme NOT REQUIRED

***Note:** Whenever the minimum utility circuit load is three times larger than the aggregated DR capacity, then some utilities waive the need for over frequency and overvoltage protection requirements.

Other Requirements

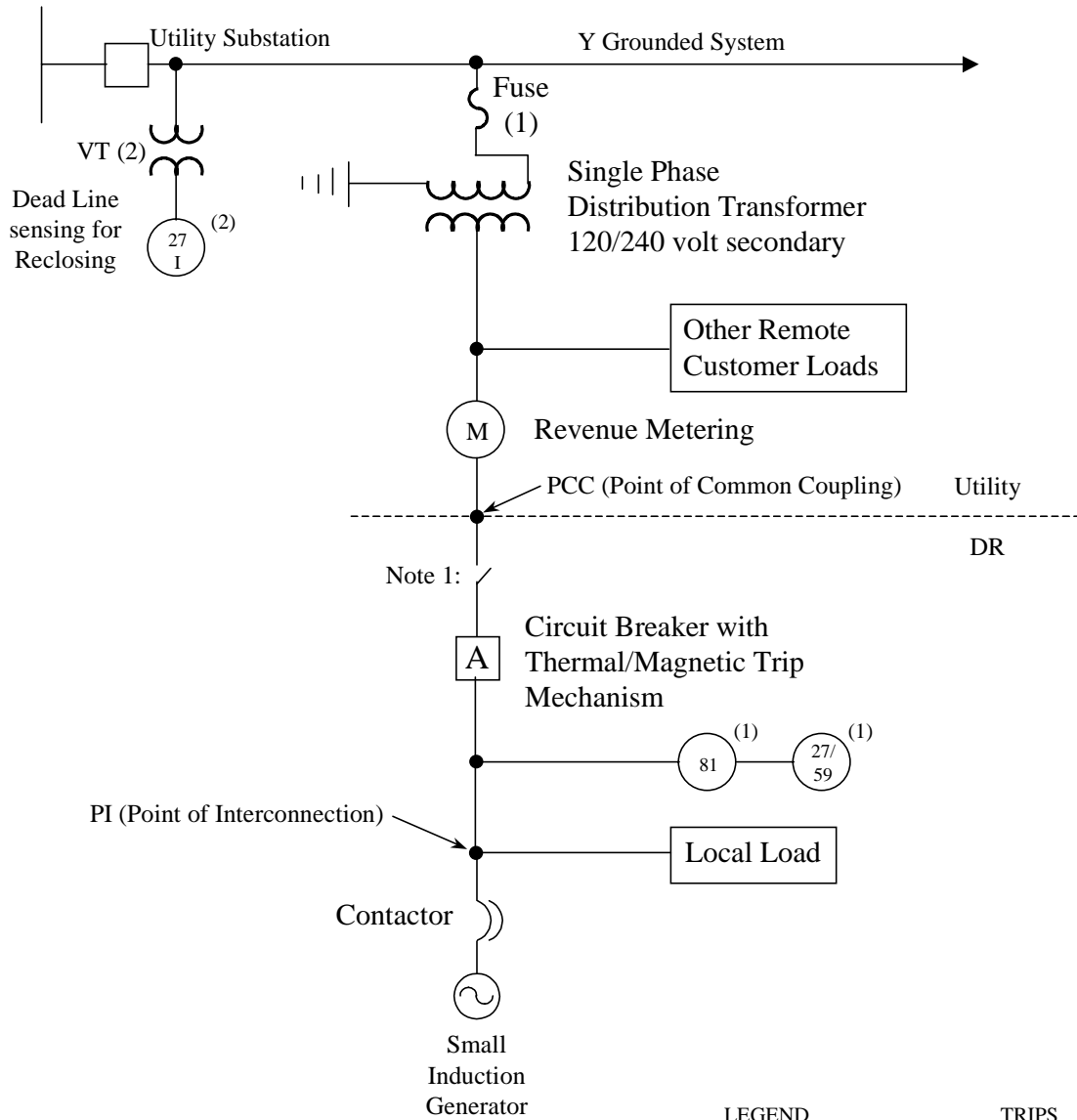
8.3.1 Accessible Lockable Disconnect

See Item 1.3.1.

8.3.2 Telemetry, Metering, Periodic Maintenance and Operating Agreements

See Item 1.3.2.

Figure 9. Small ($\leq 25\text{kVA}$) Single Phase Induction Generator



LEGEND

TRIPS

27/59	Time Under & Over voltage	A
27I	Instantaneous Undervoltage (Blocks Auto Reclose at Substation)	
81	Overfrequency & Underfrequency	A

Note 1: Accessible and lockable disconnect switch.

Note 2: DR could partially serve other remote loads on the secondary system

Note 3: For loss of utility system, DR could continue to serve local load by opening breaker A.

This presumes enough reactive is available for the induction generator.

Figure 9. Small ($\leq 25\text{ kVA}$) Single Phase Induction Generator

Issues Addressed:

Reclosing out of Synchronism (3)
Islanding (5)
Faults Within a DR Zone (15)
Isolate DR for Upstream Fault (16)
Underfrequency (28)

Protective Systems Required to Protect the Power System

The protection systems listed in this section are required to protect the utility power system from disturbances caused by DR's, or from operating the DR's under abnormal conditions.

This DR can provide energy to other remote customer loads connected to the secondary system. The DR cannot run isolated from the utility and serve these loads, because there is no electrically operated isolation device and also, the DR requires reactive support from the utility to operate.

9.1.1 Dead Line Sensing (27I) (Covers Issue #3)

This would normally not be required for a DR of this size. The DR would be expected to be off-line prior to any time delayed reclosing operation. If an immediate reclosing is utilized, then dead line sensing might be considered. Even then it is unlikely the DR will be capable of sustaining a voltage detectable at the substation when isolated from the utility, because of its relatively small size compared to the circuit load.

9.1.2 Phase Undervoltage Relaying (27)

See Item 1.1.2.

9.1.3 Phase Overvoltage relaying(59) (Covers Issues #5, 6, and 11)

See Item 1.1.3.

9.1.4 Under/Over Frequency (81) (Covers Issues #5, and 28)

See Item 1.1.4.

9.1.5 Zero Sequence Overvoltage (59G) NOT REQUIRED

This scheme is not required due to the single phase connection of transformer.

9.1.6 Breakers to be tripped by Undervoltage (27), Overvoltage (59I/T), Underfrequency (81) relays

Breaker A is tripped by the 27/59, and 81 relays, because this is the only electrically operated device that can isolate the DR from the utility system.

9.1.7 Secondary Breaker Overcurrent Device (Covers Issue # 15 and 16)

Breaker A will isolate faults beyond the point of common coupling. The breaker's trip devices should also be set to coordinate with utility system protective devices and protective devices within the local load.

Other Protection Systems

No other protection systems are shown in Figure 9., because of the relatively simple configuration.

Minimum System Protection Technical Requirements for Interconnection to the Utility

9.2.1 Dead Line Sensing NOT REQUIRED

9.2.2 Undervoltage Protection

See Item 1.2.2.

9.2.3 Overvoltage Protection

See Item 1.2.3.

9.2.4 Under and Over Frequency Protection

See Item 1.2.4.

9.2.5 Zero Sequence Overvoltage NOT REQUIRED

9.2.6 Protection for Faults on the DR System

Breaker A provides the necessary isolation for faults beyond the point of common coupling to the DR.

9.2.7 Transfer Trip Scheme NOT REQUIRED

Other Requirements

9.3.1 Accessible Lockable Disconnect

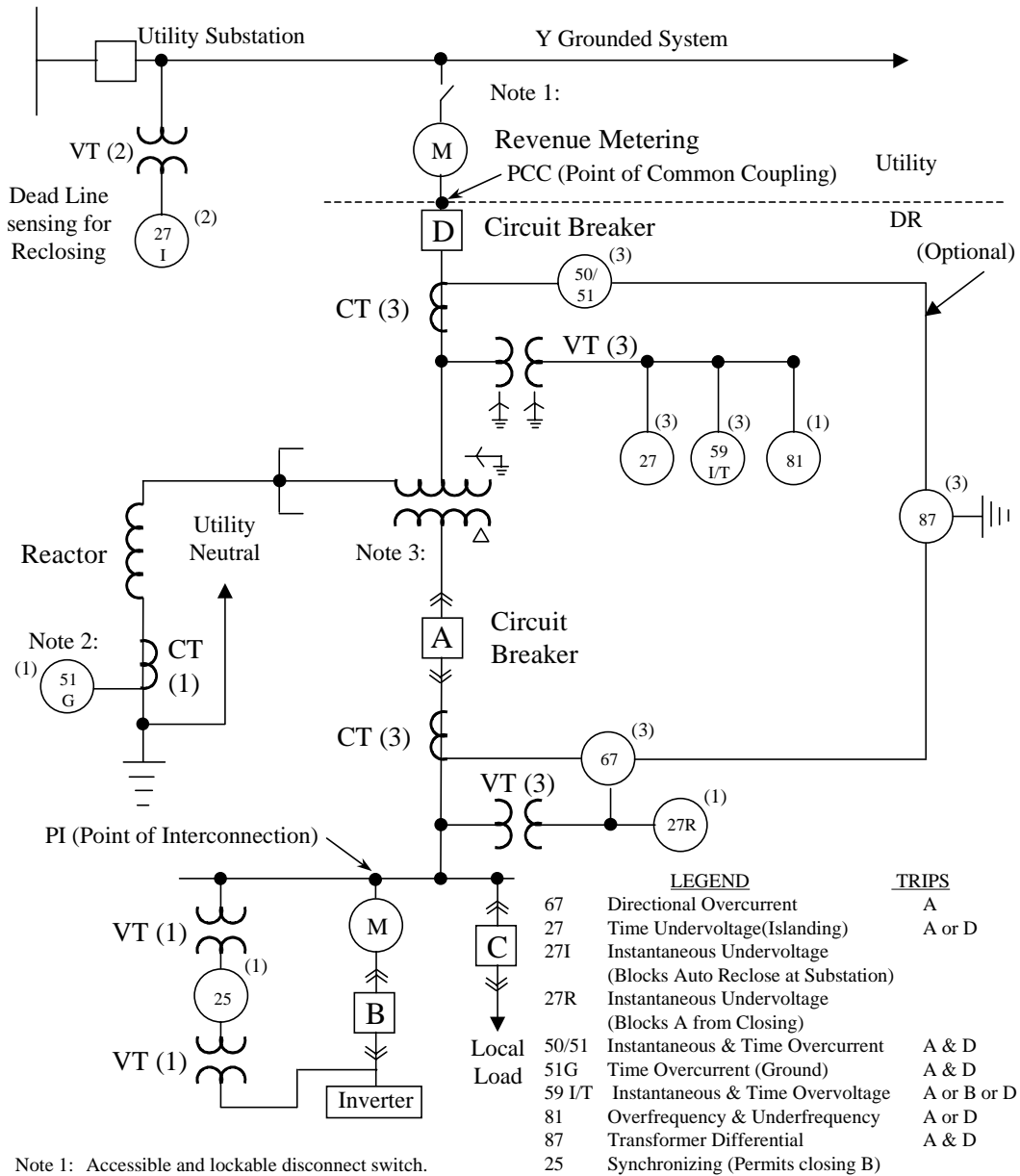
See Item 1.3.1.

9.3.2 Telemetering, Metering, Periodic Maintenance and Operating Agreements

Telemetering would normally not be done for such a small DR. However, local circumstances may dictate that some form of telemetering be installed.

See Item 1.3.2.

Detailed Discussion of System Protection Used in Figure 10. Large Three Phase Inverter (> 100kVA) and Grounded Wye – Delta Transformer with Differential Relay



Note 1: Accessible and lockable disconnect switch.

Note 2: Reduces Zero Sequence current flow to distribution line faults.

Note 3: DR's using Wye-Delta transformations can run isolated and serve other remote loads.

However, the size of the reactor could limit the amount of load served remotely.

Note 4: For loss of utility system, DR could continue to serve local load by opening breaker A or breaker D

Figure 10. Large Three Phase Inverter (> 100 kVA) and Grounded Wye - Delta Transformer
with Differential Relay

Issues Addressed:

- **Reclosing out of Synchronism (3)**
- **Islanding (5)**
- **Equipment Overvoltage (6)**
- **Voltage Regulation Malfunction due to DR's (11)**
- **Cold Load Pick-up (14)**
- **Faults Within a DR Zone (15)**
- **Isolate DR for Upstream Fault (16)**
- **Fault Causes Voltage Dip – Trips DR (17)**
- **Loss of Exciter Causes Low Voltage (22)**
- **Inrush Of Induction Machines Causes Voltage Dips (23)**
- **Underfrequency (28)**

Protective Systems Required to Protect the Power System

The protection systems listed in this section are required to protect the utility power system from disturbances caused by DR's, or from operating the DR's under abnormal conditions. This Figure differs from Figures 1. and 3. in that the transformer is connected grounded wye – delta. The grounded wye primary permits the DR to serve load connected line-to-ground, while being isolated from the utility source. The reactor in the neutral of the transformer primary limits the amount of zero sequence current that can be supplied by this transformer into utility system faults. However, the reactor can severely limit the amount of line-to-ground load that can be served from this transformer.

Note that the configuration is similar to Figure 4. with the exception of the grounding reactor and the 51G relay in the neutral of the transformer. This configuration has some issues worth reviewing. The grounded wye-delta transformer configuration becomes a ground current source. Coordination studies must take this into account. At present, some utilities will not ordinarily permit this connection, because of the “desensitizing” effect this ground source has on other ground relays at the substation. Again, the reactor reduces the “desensitizing” effect by limiting the amount of ground current that can be supplied by the transformer.

10.1.1 Dead Line Sensing (27I) (Covers Issue #3)

See Item 1.1.1.

10.1.2 Phase Undervoltage Relaying (27) (Covers Issues #5, 11, 14, 17, 22, & 23)

See Item 1.1.2.

10.1.3 Phase Overvoltage relaying (59I/T) (Covers Issues # 5, 6, & 11)

See Item 1.1.3.

10.1.4 Under/Over Frequency (81) (Covers Issues #5, and 28)

See Item 1.1.4.

10.1.5 Zero Sequence Overvoltage (59G) (Covers Issues #5, 6, and 16) (NOT REQUIRED for this Figure)

This scheme is not required due to wye connected primary of transformer.

10.1.6 Breakers to be tripped by Undervoltage (27), Overvoltage (59I/T), Underfrequency (81) relays

See Item 1.1.6.

10.1.7 Transformer High Side Overcurrent Relays 50/51, 51G (Covers Issues #15 and 16)

This system provides protection for transformer internal faults and faults within the zone between breaker A and the transformer. If transformer differential relays (87) are used, the 50/51 relays are strictly backup protection for faults within the DR system. The 50/51 and/or 51G relays may trip for faults on the utility system, if the DR generation can contribute sufficient fault current and generation overcurrent protection at breaker B is not coordinated with the 50/51 relays to trip first. Also see Item 1.1.13.

Other Protection Systems

The remaining protection systems, shown in Figure 10., are typically used to protect the DR from faults and facilitate operating the DR system. However, they are not required for interconnection.

10.1.8 Transformer Differential Relays (87) (Covers Issue #15)

These relays sense faults within their zone of protection, that is, between the transformer high side CTs and the CTs on breaker A. They provide high speed clearing for faults on the transformer and all of the bus within the protected zone. Depending on relay setting, they may or may not sense ground faults due to limited current flowing through the reactor. These relays will normally trip breaker D and breaker A.

10.1.9 Transformer Neutral Ground Relays (51G) (Covers Issue #1)

These relays are not needed due to the ungrounded delta configuration of the transformer.

10.1.10 Transformer Secondary Overcurrent Relays (51) (Covers Issue #15)

These relays are not shown. Refer to Figure 1. for typical connection.

See Item 1.1.10 for operation.

10.1.11 Instantaneous Overvoltage to Prevent Closing (27R)

See Item 1.1.11.

10.1.12 Synchronizing Relay (25)

See Item 1.1.12.

10.1.13 Directional Overcurrent (67) (Covers Issues #15, and 16)

See Item 1.1.13.

Minimum System Protection Technical Requirements for Interconnection to the Utility

10.2.1 Out-of-Synchronism Reclosing Protection

See Item 1.2.1.

10.2.2 Undervoltage Protection

See Item 1.2.2.

10.2.3* Overvoltage Protection

See Item 1.2.3.

10.2.4* Under and Over Frequency Protection

See Item 1.2.4.

10.2.5 Zero Sequence Overvoltage is NOT REQUIRED

10.2.6 Protection for Faults on the DR System

See Item 1.2.6.

10.2.7 Transfer Trip Scheme NOT REQUIRED

***Note:** Whenever the minimum utility circuit load is three times larger than the aggregated DR capacity, then some utilities waive the need for over frequency and overvoltage protection requirements.

Other Requirements

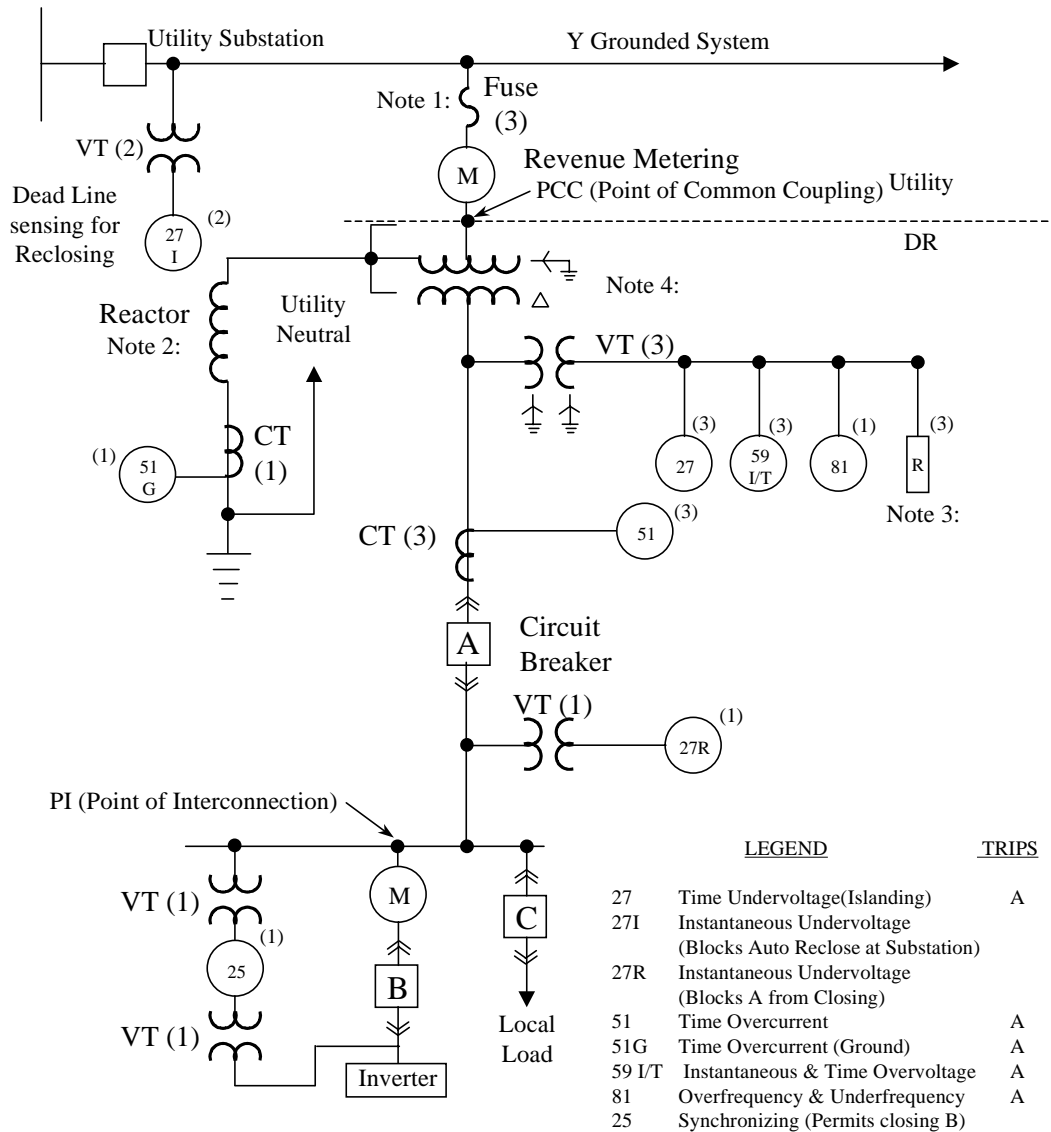
10.3.1 Accessible Lockable Disconnect

See Item 1.3.1.

10.3.2 Telemetry, Metering, Periodic Maintenance and Operating Agreements

See Item 1.3.2.

Detailed Discussion of System Protection Used in Figure 11. Small Three Phase Inverter ($\leq 100\text{kVA}$) and Grounded Wye – Delta Transformer



- Note 1: Accessible and lockable fused disconnect switch.
 Note 2: Reduces Zero Sequence current flow to distribution line faults.
 Note 3: Ferroresonance suppression resistors.
 Note 4: DR's using Wye-Delta transformations can run isolated and serve other remote loads.
 However, the size of the reactor could limit the amount of load served remotely.
 Note 5: For loss of utility system, DR could continue to serve local load by opening breaker A.

Figure 11. Small Three Phase Inverter ($\leq 100\text{ kVA}$) Grounded Wye - Delta Transformer
Protected by Fuses

Issues Addressed:

- **Reclosing out of Synchronism (3)**
- **Islanding (5)**
- **Equipment Overvoltage (6)**
- **Voltage Regulation Malfunction due to DR's (11)**
- **Cold Load Pick-up (14)**
- **Faults Within a DR Zone (15)**
- **Isolate DR for Upstream Fault (16)**
- **Fault Causes Voltage Dip – Trips DR (17)**
- **Loss of Exciter Causes Low Voltage (22)**
- **Inrush Of Induction Machines Causes Voltage Dips (23)**
- **Underfrequency (28)**

Protective Systems Required to Protect the Power System

The protection systems listed in this section are required to protect the utility power system from disturbances caused by DR's, or from operating the DR's under abnormal conditions. This Figure differs from Figures 1. and 3. in that the transformer is connected grounded wye – delta. The grounded wye primary permits the DR to serve load connected line-to-ground, while being isolated from the utility source. The reactor in the neutral of the transformer primary limits the amount of zero sequence current that can be supplied by this transformer into utility system faults. However, the reactor can severely limit the amount of line-to-ground load that can be served from this transformer.

Note that the configuration is similar to Figure 4. with the exception of the grounding reactor and the 51G relay in the neutral of the transformer. Also, the voltage and frequency relays are connected to the transformer secondary; and a set of surge suppression resistors has been installed due to the ungrounded delta secondary. This configuration has some issues worth reviewing. The grounded wye-delta transformer configuration becomes a ground current source. Coordination studies must take this into account. At present, some utilities will not ordinarily permit this connection, because of the “desensitizing” effect this ground source has on other ground relays at the substation. Again, the reactor reduces the “desensitizing” effect by limiting the amount of ground current that can be supplied by the transformer.

11.1.1 Dead Line Sensing (27I) (Covers Issue #3)

See Item 1.1.1.

11.1.2 Phase Undervoltage Relaying (27) (Covers Issues #5, 11, 14, 17, 22, & 23)

See Item 1.1.2.

11.1.3 Phase Overvoltage relaying (59I/T) (Covers Issues # 5, 6, & 11)

See Item 1.1.3.

11.1.4 Under/Over Frequency (81) (Covers Issues #5, and 28)

See Item 1.1.4.

11.1.5 Zero Sequence Overvoltage (59G) (Covers Issues #5, 6, and 16) (NOT REQUIRED for this Figure)

This scheme is not required due to wye connected primary of transformer.

11.1.6 Breakers to be tripped by Undervoltage (27), Overvoltage (59I/T), Underfrequency (81) relays

See Item 1.1.6.

11.1.7 Fuses, and Transformer High Side Overcurrent Relay 51G (Covers Issues #15 and 16)

This system provides protection for transformer internal faults and faults within the zone between breaker A and the transformer. The 51G relays may trip for faults on the utility system, if the DR generation can contribute sufficient fault current and generation overcurrent protection at breaker B is not coordinated with the 50/51 relays to trip first. Also see Item 1.1.13.

Other Protection Systems

The remaining protection systems, shown in Figure 11., are typically used to protect the DR from faults and facilitate operating the DR system. However, they are not required for interconnection.

11.1.8 Transformer Differential Relays (87) Not Applicable

11.1.9 Transformer Neutral Ground Relays (51G) (Covers Issue #1)

These relays are not needed due to the ungrounded delta configuration of the transformer.

11.1.10 Transformer Secondary Overcurrent Relays (51) (Covers Issue #15)

See Item 1.1.10.

11.1.11 Instantaneous Overvoltage to Prevent Closing (27R)

See Item 1.1.11.

11.1.12 Synchronizing Relay (25)

See Item 1.1.12.

Minimum System Protection Technical Requirements for Interconnection to the Utility

11.2.1 Out-of-Synchronism Reclosing Protection

See Item 1.2.1.

11.2.2 Undervoltage Protection

See Item 1.2.2.

11.2.3* Overvoltage Protection

See Item 1.2.3.

11.2.4* Under and Over Frequency Protection

See Item 1.2.4.

11.2.5 Zero Sequence Overvoltage is NOT REQUIRED

11.2.6 Protection for Faults on the DR System

See Item 1.2.6.

11.2.7 Transfer Trip Scheme NOT REQUIRED

***Note:** Whenever the minimum utility circuit load is three times larger than the aggregated DR capacity, then some utilities waive the need for over frequency and overvoltage protection requirements.

Other Requirements

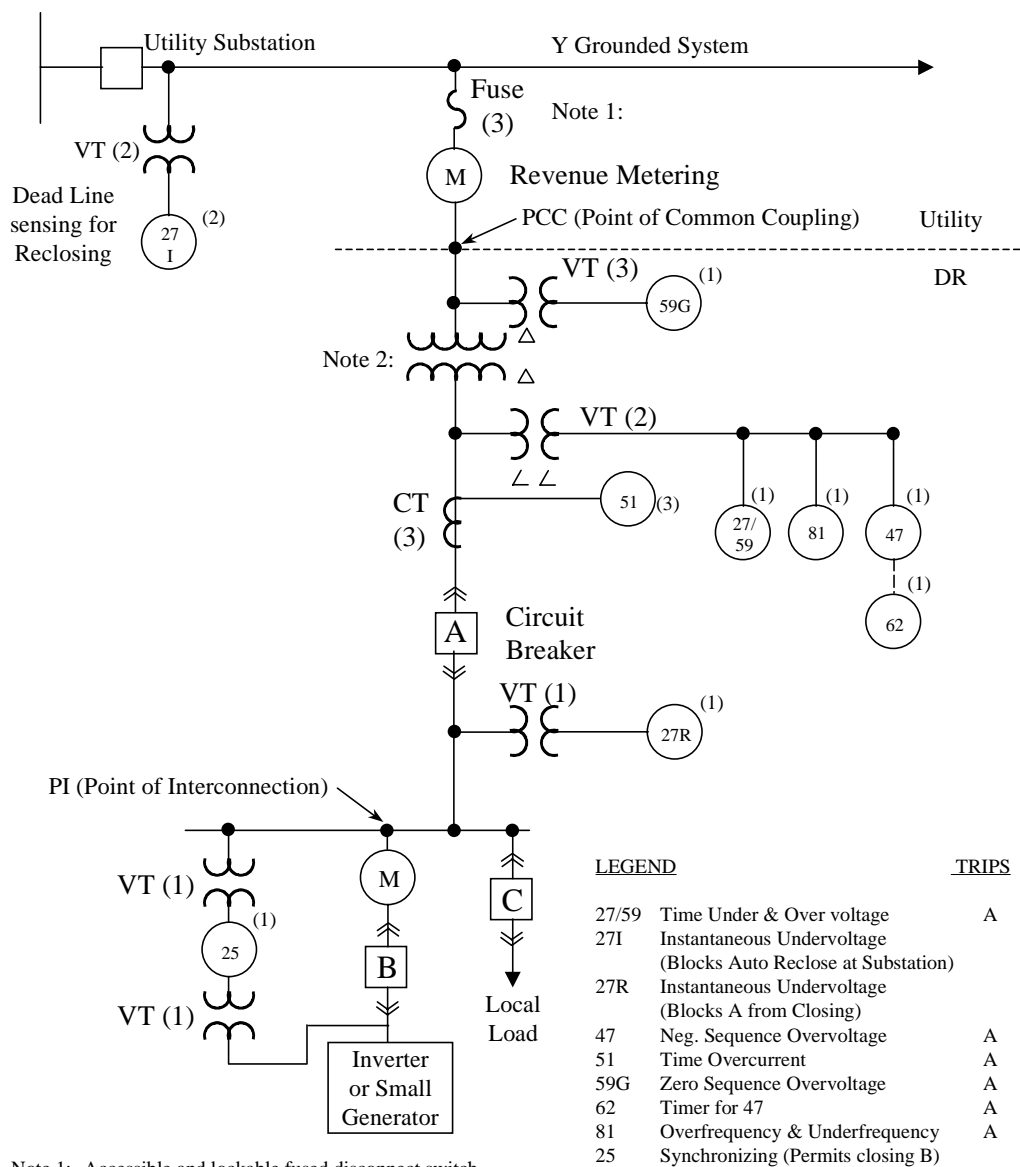
11.3.1 Accessible Lockable Disconnect

See Item 1.3.1.

11.3.2 Telemetry, Metering, Periodic Maintenance and Operating Agreements

See Item 1.3.2.

Detailed Discussion of System Protection Used in Figure 12. Small Three Phase Inverter ($\leq 100\text{kVA}$) Connected to a Delta - Delta Transformer



Note 1: Accessible and lockable fused disconnect switch.

Note 2: For Delta - Delta transformations there is no ground fault current contribution for primary faults, therefore this transformer connection cannot be used for DR's operating isolated and serving other remote line to ground load.

Note 3: For loss of utility system, DR could continue to serve local load by opening breaker A.

Figure 12. Small Three Phase Inverter ($\leq 100\text{ kVA}$) or Synchronous Generator ($\leq 100\text{ kVA}$) connected to Delta - Delta Transformer

Issues Addressed:

- **Reclosing out of Synchronism (3)**
- **Islanding (5)**
- **Equipment Overvoltage (6)**
- **Voltage Regulation Malfunction due to DR's (11)**
- **Cold Load Pick-up (14)**
- **Faults Within a DR Zone (15)**
- **Isolate DR for Upstream Fault (16)**
- **Fault Causes Voltage Dip – Trips DR (17)**
- **Loss of Exciter Causes Low Voltage (22)**
- **Inrush Of Induction Machines Causes Voltage Dips (23)**
- **Underfrequency (28)**

Protective Systems Required to Protect the Power System

The protection systems listed in this section are required to protect the utility power system from disturbances caused by DR's, or from operating the DR's under abnormal conditions. This Figure is similar to Figure 11. but differs in that the transformer is connected Delta - Delta. The ungrounded delta prevents line-to-ground loads from being served from this DR, while being isolated from the utility source.

This configuration has no transformer neutral ground and thus can have no 51G relay in that neutral. A zero sequence overvoltage is connected to the transformer primary VTs to detect line-to-ground faults that persist after the utility source is isolated. Also, there is no set of surge suppression resistors in the secondary of the VTs connected to the transformer secondary.

12.1.1 Dead Line Sensing (27I) (Covers Issue #3)

See Item 1.1.1.

12.1.2 Phase Undervoltage Relaying (27) (Covers Issues #5, 11, 14, 17, 22, & 23)

See Item 1.1.2.

12.1.3 Phase Overvoltage relaying (59I/T) (Covers Issues # 5, 6, & 11)

See Item 1.1.3.

12.1.4 Under/Over Frequency (81) (Covers Issues #5, and 28)

See Item 1.1.4.

12.1.5 Zero Sequence Overvoltage (59G) (Covers Issues #5, 6, and 16)

See Item 1.1.5.

12.1.6 Breakers to be tripped by Undervoltage (27), Overvoltage (59I/T), Underfrequency (81) relays

See Item 1.1.6.

12.1.7 Primary Fuses (Covers Issues #15 and 16)

The primary fuses will isolate faults beyond the point of common coupling. They should also be selected to coordinate with utility system protective devices and downstream DR devices.

Other Protection Systems

The remaining protection systems, shown in Figure 12., are typically used to protect the DR from faults and facilitate operating the DR system. However, they are not required for interconnection.

12.1.8 Transformer Differential Relays (87) Not Applicable

12.1.9 Transformer Neutral Ground Relays (51G) Not Applicable

These relays are not needed due to the ungrounded delta configuration of the transformer.

12.1.10 Transformer Secondary Overcurrent Relays (51) (Covers Issue #15)

See Item 1.1.10.

12.1.11 Instantaneous Overvoltage to Prevent Closing (27R)

See Item 1.1.11.

12.1.12 Synchronizing Relay (25)

See Item 1.1.12.

12.1.13 Negative Sequence Overvoltage (47)

This relay detects an abnormally high level of unbalanced (negative sequence) voltage. It can detect single phase conditions caused by a blown fuse or open conductor.

Minimum System Protection Technical Requirements for Interconnection to the Utility

12.2.1 Out-of-Synchronism Reclosing Protection

See Item 1.2.1.

12.2.2 Undervoltage Protection

See Item 1.2.2.

12.2.3* Overvoltage Protection

See Item 1.2.3.

12.2.4* Under and Over Frequency Protection

See Item 1.2.4.

12.2.5 Zero Sequence Overvoltage

See Item 1.2.5.

12.2.6 Protection for Faults on the DR System

See Item 1.2.6.

12.2.7 Transfer Trip Scheme NOT REQUIRED

***Note:** Whenever the minimum utility circuit load is three times larger than the aggregated DR capacity, then some utilities waive the need for over frequency and overvoltage protection requirements.

Other Requirements

12.3.1 Accessible Lockable Disconnect

See Item 1.3.1.

12.3.2 Telemetry, Metering, Periodic Maintenance and Operating Agreements

See Item 1.3.2.

Issues Addressed:

- **Reclosing out of Synchronism (3)**
- **Islanding (5)**
- **Equipment Overvoltage (6)**
- **Voltage Regulation Malfunction due to DR's (11)**
- **Cold Load Pick-up (14)**
- **Faults Within a DR Zone (15)**
- **Isolate DR for Upstream Fault (16)**
- **Fault Causes Voltage Dip – Trips DR (17)**
- **Loss of Exciter Causes Low Voltage (22)**
- **Inrush Of Induction Machines Causes Voltage Dips (23)**
- **Underfrequency (28)**

Protective Systems Required to Protect the Power System

The protection systems listed in this section are required to protect the utility power system from disturbances caused by DR's, or from operating the DR's under abnormal conditions.

This configuration is similar to Figure 1., except it is connected to a utility system that has an ungrounded delta system. Therefore, it will have no zero sequence overvoltage detection for the purposes of isolation. Zero sequence overvoltage detection is optional for the purposes of detecting an unintentional ground on the system.

13.1.1 Dead Line Sensing (27I) (Covers Issue #3)

See Item 1.1.1.

13.1.2 Phase Undervoltage Relaying (27) (Covers Issues #5, 11, 14, 17, 22, & 23)

See Item 1.1.2.

13.1.3 Phase Overvoltage relaying (59I/T) (Covers Issues # 5, 6, & 11)

See Item 1.1.3.

13.1.4 Under/Over Frequency (81) (Covers Issues #5, and 28)

See Item 1.1.4.

13.1.5 Zero Sequence Overvoltage (59G) (Covers Issue #6 and 16)

This relay senses the overvoltage that results on the two ungrounded phases when the remaining conductor is connected to ground through a low impedance path, commonly called a “ground”.

Depending on operating practices, isolation for zero sequence overvoltage may or may not be required. The DR may choose to isolate from the utility to protect the local equipment, or the utility may require the DR be isolated so that an unintentional ground can be located.

Note the zero sequence overvoltage condition can occur when the DR is still connected to the utility system (as a result of a grounded conductor) and therefore cannot be used as a means to detect isolation from the utility.

13.1.6 Breakers to be tripped by Undervoltage (27), Overvoltage (59I/T), Underfrequency (81) and Zero Sequence Overvoltage (59G) relays

See Item 1.1.6.

13.1.7 Transformer High Side Overcurrent Relays (50/51) (Covers Issues #15 and 16)

See Item 1.1.7.

Other Protection Systems

The remaining protection systems, shown in Figure 13., are typically used to protect the DR from faults and facilitate operating the DR system. However, they are not required for interconnection.

13.1.8 Transformer Differential Relays (87) (Covers Issue #15)

See Item 1.1.8.

13.1.9 Transformer Neutral Ground Relays (51G), (151G) (Covers Issue #15)

See Item 1.1.9.

13.1.10 Transformer Secondary Overcurrent Relays (51) (Covers Issue #15)

See Item 1.1.10.

13.1.11 Instantaneous Overvoltage to Prevent Closing (27R)

See Item 1.1.11.

13.1.12 Synchronizing Relay (25)

See Item 1.1.12.

13.1.13 Directional Overcurrent (67) (Covers Issues #15, and 16)

See Item 1.1.13.

Minimum System Protection Technical Requirements for Interconnection to the Utility

13.2.1 Out-of-Synchronism Reclosing Protection

See Item 1.2.1.

13.2.2 Undervoltage Protection

See Item 1.2.2.

13.2.3* Overvoltage Protection

See Item 1.2.3.

13.2.4* Under and Over Frequency Protection

See Item 1.2.4.

13.2.5 Zero Sequence Overvoltage Protection

Zero sequence overvoltage protection may be required to clear the DR unit for grounded conductors on the normally ungrounded delta utility system.

Depending on operating practices, isolation for zero sequence overvoltage may or may not be required. The DR may choose to isolate from the utility to protect the local equipment, or the utility may require the DR be isolated so that an unintentional ground can be located.

13.2.6 Protection for Faults on the DR System

See Item 1.2.6.

13.2.7 Transfer Trip Scheme NOT REQUIRED

***Note:** Whenever the minimum utility circuit load is three times larger than the aggregated DR capacity, then some utilities waive the need for over frequency and overvoltage protection requirements.

Other Requirements

13.3.1 Accessible Lockable Disconnect

See Item 1.3.1.

13.3.2 Telemetry, Metering, Periodic Maintenance and Operating Agreements

See Item 1.3.2.

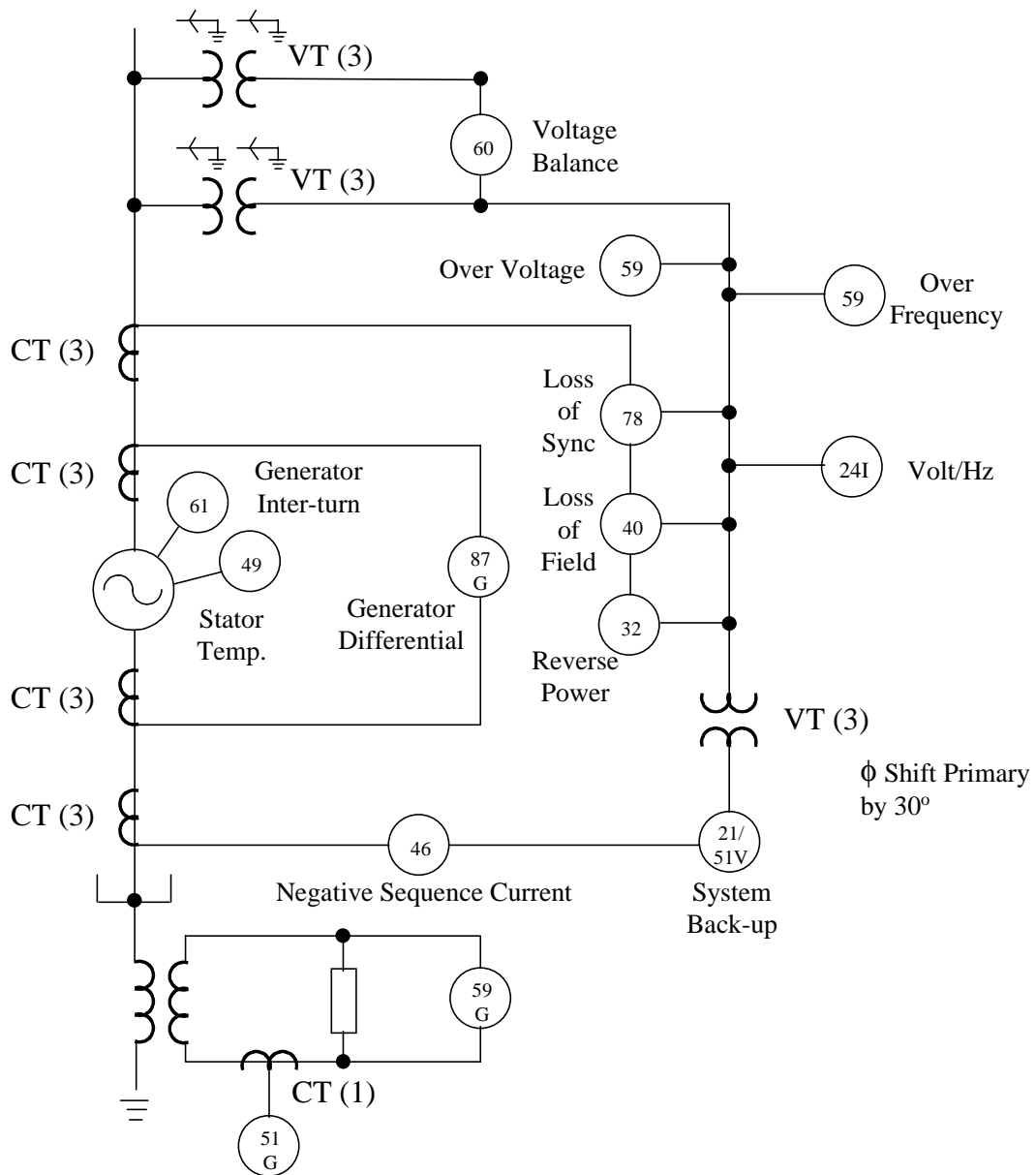


Figure 14. Typical Synchronous Generator Protection

Issues Addressed :

- **Reclosing out of Synchronism (3)**
- **Transfer Tripping (4)**
- **Islanding (5)**
- **Equipment Overvoltage (6)**
- **Voltage Regulation Malfunction due to DR's (11)**
- **Cold Load Pick-up (14)**
- **Faults Within a DR Zone (15)**
- **Isolate DR for Upstream Fault (16)**
- **Fault Causes Voltage Dip – Trips DR (17)**
- **Loss of Exciter Causes Low Voltage (22)**
- **Inrush Of Induction Machines Causes Voltage Dips (23)**
- **Underfrequency (28)**

Protective Systems Required to Protect the Power System

The protection systems listed in this section are required to protect the utility power system from disturbances caused by DR's, or from operating the DR's under abnormal conditions. They are identical to the systems shown in Figure 13. with the exception of Transfer Trip Relaying. Please refer to the Detailed Discussion of System Protection for Figure 13. for System Protection shown in Figure 15.

See Items 13.1.1 through 13.1.7 of Figure 13.

15.1.1 Transfer Trip Relaying (Covers Issue #4)

For systems where DR's are not permitted to operate as an island, transfer tripping from the utility's breaker to the DR may be needed. The DR is automatically removed from the utility's system when the utility's breaker opens.

The Transmitter (Tx) is keyed to the audio tone trip frequency when the substation breaker is opened for any reason. Upon detection of the trip frequency, the receiver (Rx) closes contacts that will trip selected breakers to isolate the generation from the utility system.

Typically two audio frequencies are used. Under normal conditions, a guard frequency is transmitted from the transmitter to the receiver. As long as the receiver continues to receive the guard frequency from the transmitter, the receiver transmits a guard frequency back to the transmitter. If the transmitter fails to receive the guard frequency from the receiver, an alarm is generated. By this re-transmitting of the guard frequency by the receiver, the integrity of the communication channel is monitored.

Other Protection Systems

The remaining protection systems, shown in Figure 15., are typically used to protect the DR from faults and facilitate operating the DR system. However, they are not required for interconnection. They are similar to the schemes shown in Figure 13.

Minimum System Protection Technical Requirements for Interconnection to the Utility

15.2.1 Out-of-Synchronism Reclosing Protection

See Item 13.2.1.

15.2.2 Undervoltage Protection

See Item 13.2.2.

15.2.3* Overvoltage Protection

See Item 13.2.3.

15.2.4* Under and Over Frequency Protection

See Item 13.2.4.

15.2.5 Zero Sequence Overvoltage Protection

See Item 13.2.5.

15.2.6 Protection for Faults on the DR System

See Item 13.2.6.

15.2.7 Transfer Trip Scheme

Whenever the aggregated generation capacity exceeds the minimum utility circuit load, the utility may require a transfer trip scheme to isolate the DR from the utility system when the

substation breaker is open. See Figure 15. There may be cases when the DR can serve an islanded load as in Figure 1., if arrangements have been agreed to by the utility and the DR owner.

***Note:** Whenever the minimum utility circuit load is three times larger than the aggregated DR capacity, then some utilities waive the need for over frequency and overvoltage protection requirements.

Other Requirements

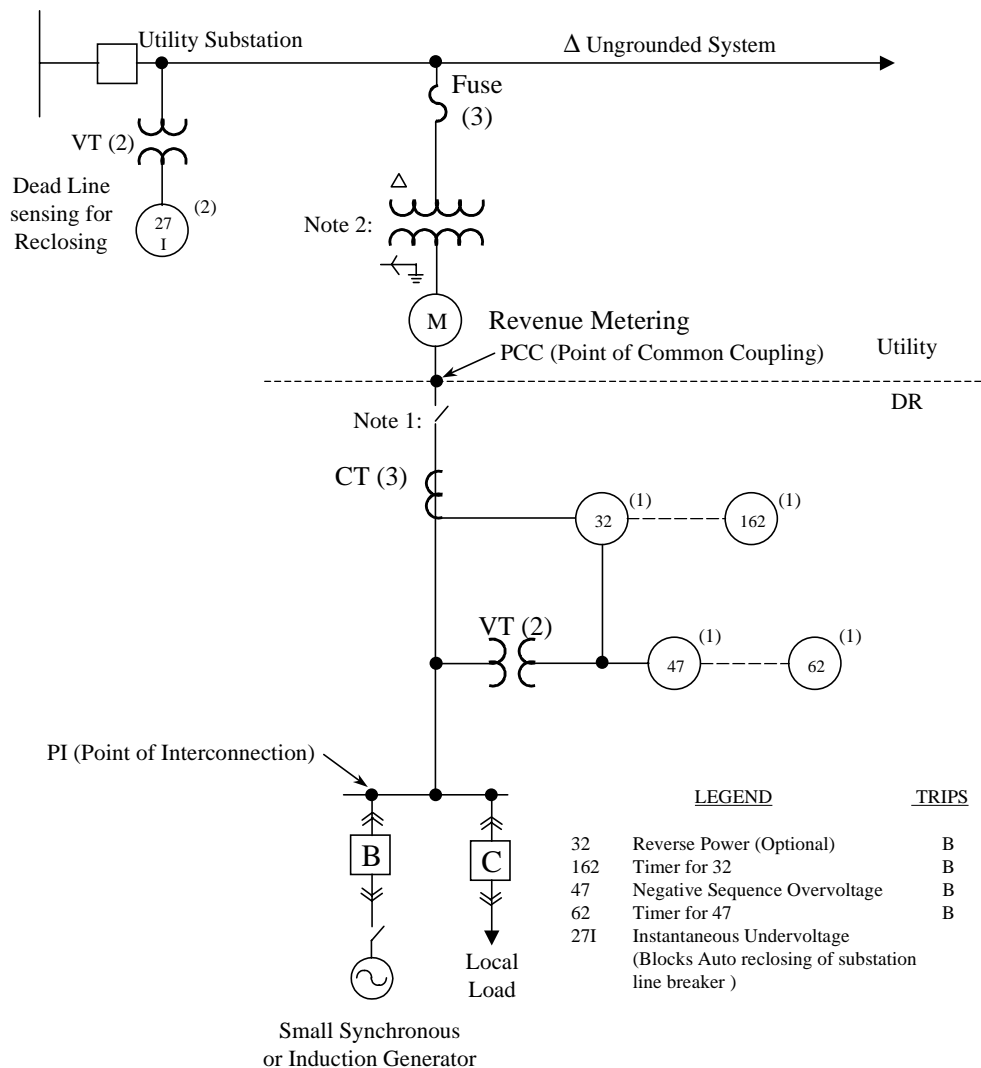
15.3.1 Accessible Lockable Disconnect

See Item 13.3.3.

15.3.2 Telemetry, Metering, Periodic Maintenance and Operating Agreements

See Item 13.3.2.

Figure 16. Small Synchronous or Induction Generator (10-100kVA) Connected to the Primary



- Note 1: Alternate location for accessible and lockable disconnect switch.
- Note 2: For Delta- Wye transformations, there is no ground fault current contribution for primary faults. This transformer connection cannot be used for DR's operating isolated and serving other remote load connected phase to phase.
- Note 3: For loss of utility system, the DR cannot automatically serve local load because there is no isolation breaker. However, if the manual disconnect is open (see Note 1) local load can be served by the DR.

Figure 16. Small Synchronous (≤ 100 kVA) or Induction (≤ 100 kVA) Three-Phase Generator connected to Primary

Issues Addressed:

- **Reclosing out of Synchronism (3)**
- **Islanding (5)**
- **Faults Within a DR Zone (15)**
- **Isolate DR for Upstream Fault (16)**

Protective Systems Required to Protect the Power System

The protection systems listed in this section are required to protect the utility power system from disturbances caused by DR's, or from operating the DR's under abnormal conditions. Because this is a relatively small DR, and will have minimal effect on the operation of the utility system, a simplified protection system is employed. A reverse power relay is used to prevent power flow from the DR to the utility system.

16.1.1 Dead Line Sensing (27I) (Covers Issue #3)

This would normally not be required for a DR of this size. The DR would be expected to be off-line prior to any time delayed reclosing operation. If an immediate reclosing is utilized, then dead line sensing might be considered. Even then it is unlikely the DR will be capable of sustaining a voltage detectable at the substation when isolated from the utility, because of its relatively small size compared to the circuit load.

16.1.2 Phase Undervoltage Relaying (27) NOT REQUIRED

16.1.3 Phase Overvoltage relaying(59I/T) NOT REQUIRED

16.1.4 Under/Over Frequency (81) NOT REQUIRED

16.1.5 Zero Sequence Overvoltage (59G) NOT REQUIRED

16.1.6 Reverse Power Relay (32) (Covers Issue #5)

This device senses powerflow to the utility system and causes breaker B to trip. A timing relay is utilized to override the transient powerflow that occurs during system faults that are successfully isolated by other devices on the utility system.

16.1.7 Breakers to be tripped by 32 relay

Breaker B is required to be tripped by the 32 relay, since this is the only electrically operated device that can isolate the DR from the utility system.

16.1.8 Primary Fuses (Covers Issues #15 and 16)

The primary fuses will isolate faults beyond the point of common coupling. They should also be selected to coordinate with utility system protective devices and downstream DR devices.

Other Protection Systems

The remaining protection systems, shown in Figure 16., are typically used to protect the DR from faults and facilitate operating the DR system. However, they are not required for interconnection.

16.1.7 Negative Sequence Overvoltage (47)

This relay can detect blown fuses or dead phases on the primary of the transformer. It would be normally connected to trip breaker B. It may also be prudent to trip breaker C to protect the load from the sometimes damaging effects of single phasing.

16.1.8 Transformer Differential Relays (87) Not Applicable

16.1.9 Transformer Neutral Ground Relays (51G), (151G) Not Applicable

16.1.10 Transformer Secondary Overcurrent Relays (51) Not Applicable

16.1.11 Instantaneous Overvoltage to Prevent Closing (27R) Not Applicable

16.1.12 Synchronizing Relay (25)

See Item 5.1.12.

Minimum System Protection Technical Requirements for Interconnection to the Utility

16.2.1 Reverse Power Protection

See Item 5.2.1.

16.2.2 Undervoltage Protection NOT REQUIRED

16.2.3 Overvoltage Protection NOT REQUIRED

16.2.4 Under and Over Frequency Protection NOT REQUIRED

16.2.5 Zero Sequence Overvoltage NOT REQUIRED

16.2.6 Protection for Faults on the DR System

Fuses provide the necessary isolation for faults beyond the point of common coupling to the DR.

16.2.7 Transfer Trip Scheme NOT REQUIRED

Other Requirements

16.3.1 Accessible Lockable Disconnect

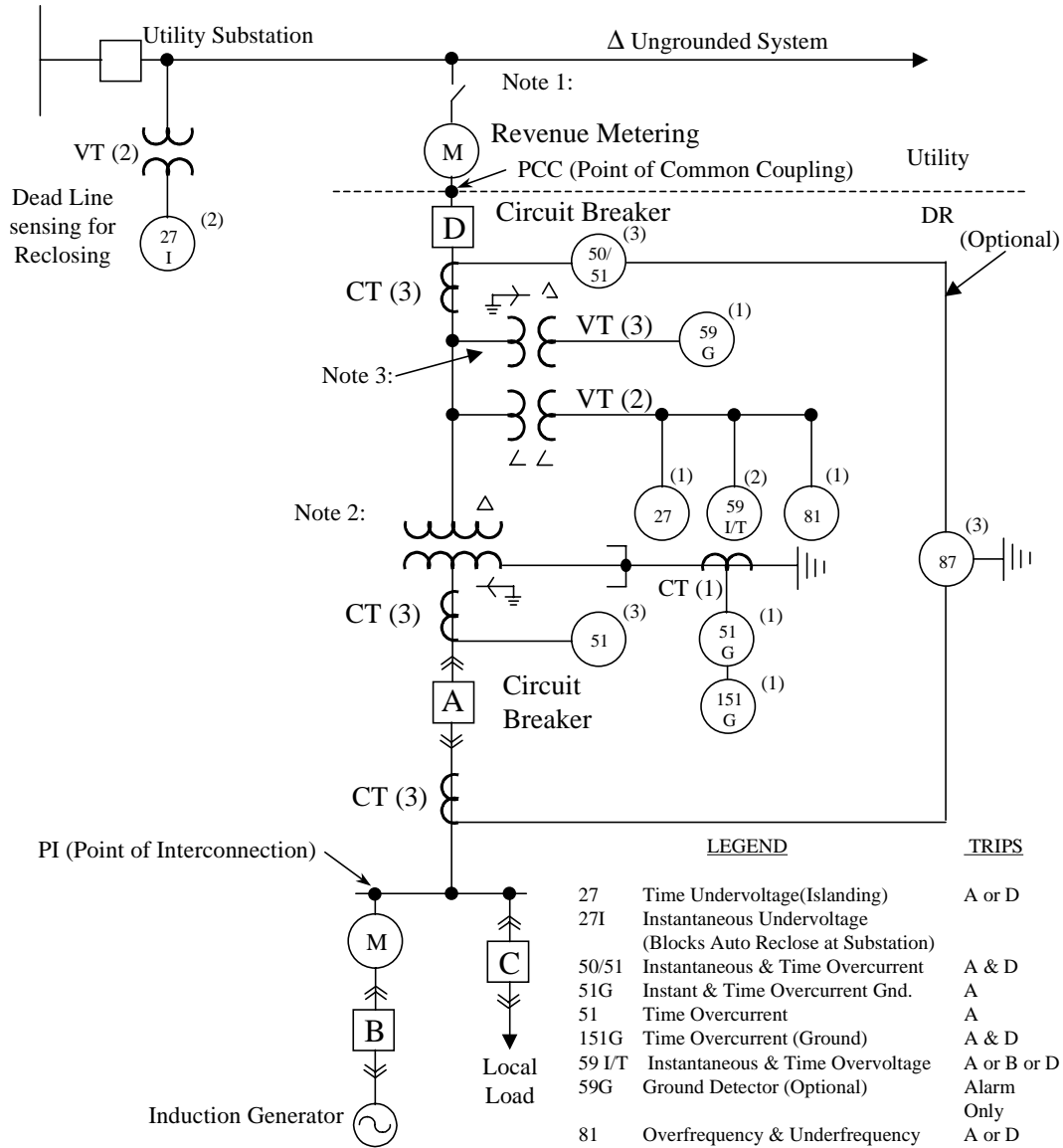
See Item 1.3.1.

16.3.2 Telemetry, Metering, Periodic Maintenance and Operating Agreements

Telemetry would normally not be done for such a small DR. However, local circumstances may dictate that some form of telemetry be installed.

See Item 1.3.2.

Detailed Discussion of System Protection Used in Figure 17. Large Induction Generator (1-5 MVA) Connected to the Primary



Note 1: Accessible and lockable disconnect switch.

Note 2: For Delta- Wye transformations, there is no ground fault current contribution for primary faults. This transformer connection can be used for DR's operating isolated and serving other remote load connected line to line.

Note 3: Secondary Connected Broken Delta

Note 4: For loss of utility system, DR could continue to serve load by opening breaker A or breaker D. This assumes power factor correction capacitors provide enough reactive.

Figure 17. Large Induction Generator (1 - 5 MVA) connected to the Primary

Issues Addressed:

- **Reclosing out of Synchronism (3)**
- **Islanding (5)**
- **Equipment Overvoltage (6)**
- **Voltage Regulation Malfunction due to DR's (11)**
- **Cold Load Pick-up (14)**
- **Faults Within a DR Zone (15)**
- **Isolate DR for Upstream Fault (16)**
- **Fault Causes Voltage Dip – Trips DR (17)**
- **Loss of Exciter Causes Low Voltage (22)**
- **Inrush Of Induction Machines Causes Voltage Dips (23)**
- **Underfrequency (28)**

Protective Systems Required to Protect the Power System

Figure 17. consists of a large induction generator connected to the primary, similar to the synchronous generator shown in Figure 13. The minimal technical requirements for interconnection are similar. The transformer is however shown as being solidly grounded.

The protection systems listed in this section are required to protect the utility power system from disturbances caused by DR's, or from operating the DR's under abnormal conditions.

17.1.1 Dead Line Sensing (27I) (Covers Issue #3)

Some utilities may not require this since an induction generator will typically lose excitation quickly after loss of the source voltage.

See Item 13.1.1.

17.1.2 Phase Undervoltage Relaying (27) (Covers Issues #5, 11, 14, 17, 22, & 23)

See Item 13.1.2.

17.1.3 Phase Overvoltage relaying(59I/T) (Covers Issues # 5, 6 & 11)

See Item 13.1.3.

17.1.4 Under/Over Frequency (81) (Covers Issues #5, and 28)

See Item 13.1.4.

17.1.5 Zero Sequence Overvoltage (59G) (Covers Issues #6, and 16)

See Item 13.1.5.

17.1.6 Breakers to be tripped by Undervoltage (27), Overvoltage (59I/T), Underfrequency (81), Zero Sequence Overvoltage (59G), relays

See Item 13.1.6.

17.1.7 Transformer High Side Overcurrent Relays (50/51) (Covers Issues #15 and 16)

See Item 13.1.7.

Other Protection Systems

The remaining protection systems, shown in Figure 17., are typically used to protect the DR from faults and facilitate operating the DR system. However, they are not required for interconnection.

17.1.8 Transformer Differential Relays (87) (Covers Issue #15)

These relays sense faults within their zone of protection, that is, between the transformer high side CTs and the CTs on breaker A. They provide high speed clearing for faults on the transformer and all of the bus within the protected zone. These relays will normally trip breaker D and breaker A. Note that this differs from Figure 13. in that this transformer is solidly grounded.

17.1.9 Transformer Neutral Ground Relay (51G), (151G) (Covers Issue #15)

See Item 13.1.9.

17.1.10 Transformer Secondary Overcurrent Relays (51) (Covers Issue #15)

See Item 13.1.10.

17.1.11 Instantaneous Overvoltage to Prevent Closing (27R)

Not normally required for an induction generator since synchronizing is not needed when closing breaker A. See Item 13.1.11 for comparison to synchronous generator.

17.1.12 Synchronizing Relay (25)

Not required for an induction generator. See Item 13.1.12 for comparison to synchronous generator.

Minimum System Protection Technical Requirements for Interconnection to the Utility

17.2.1 Out-of-Synchronism Reclosing Protection

See Item 13.2.1.

17.2.2 Undervoltage Protection

See Item 13.2.2.

17.2.3* Overvoltage Protection

See Item 13.2.3.

17.2.4* Under and Over Frequency Protection

See Item 13.2.4.

17.2.5 Zero Sequence Overvoltage Protection

See Item 13.2.5.

17.2.6 Protection for Faults on the DR System

See Item 13.2.6.

17.2.7 Transfer Trip Scheme NOT REQUIRED

***Note:** Whenever the minimum utility circuit load is three times larger than the aggregated DR capacity, then some utilities waive the need for over frequency and overvoltage protection requirements.

Other Requirements

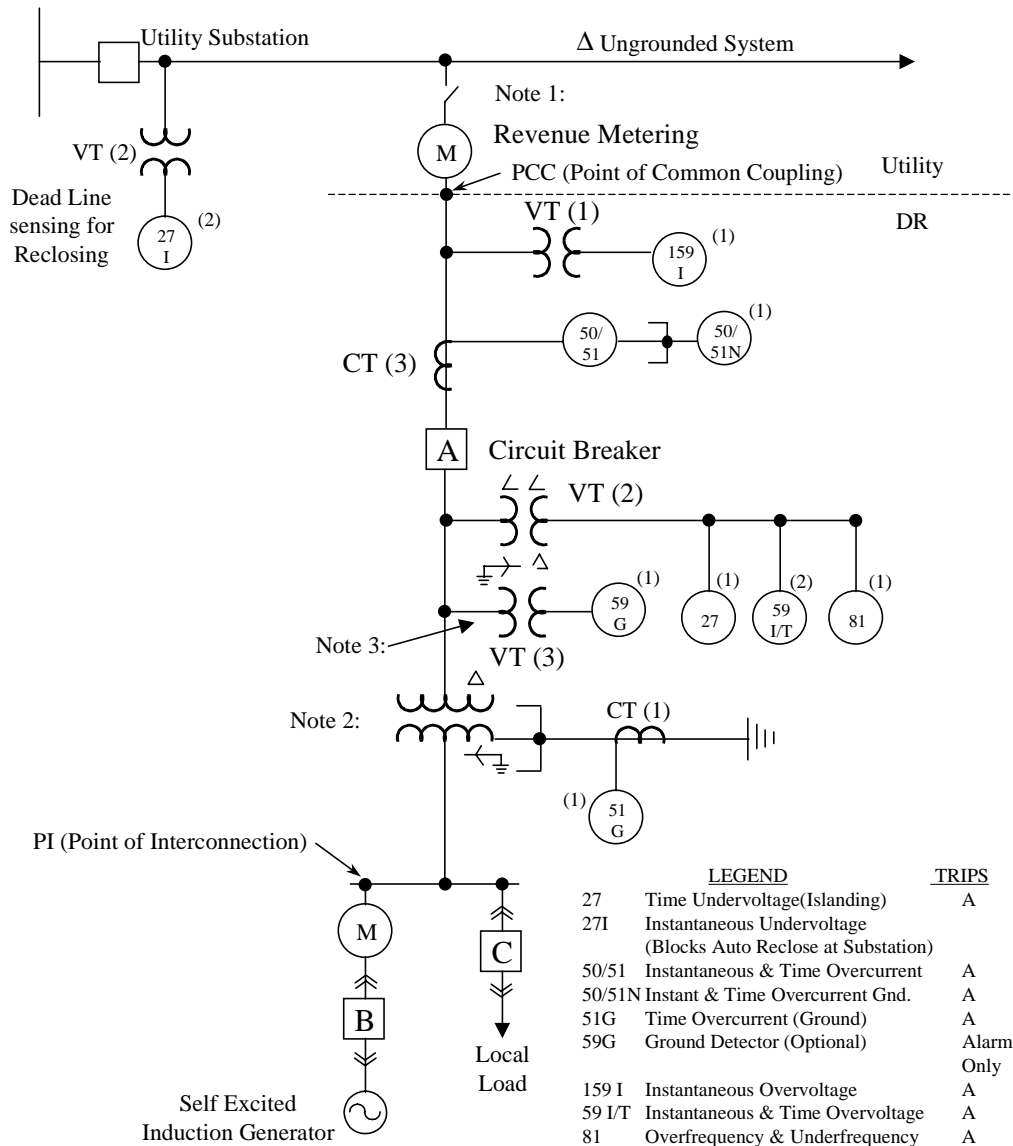
17.3.1 Accessible Lockable Disconnect

See Item 13.3.1.

17.3.2 Telemetry, Metering, Periodic Maintenance and Operating Agreements

See Item 13.3.2.

Detailed Discussion of System Protection Used in Figure 18. Large Self Excited Induction Generator (1-5 MVA) Connected to the Primary Serving other Isolated Loads



- Note 1: Accessible and lockable disconnect switch.
 Note 2: For Delta- Wye transformations, there is no ground fault current contribution for primary faults. This transformer connection can be used for DR's operating isolated and serving other remote load connected line to line.
 Note 3: Secondary Connected Broken Delta
 Note 4: For loss of utility system, DR could continue to serve local load by opening breaker A.

Figure 18. Large Self Excited Induction Generator (1 - 5 MVA) with High - Side Breaker (only) and serving other isolated remote loads.

Issues Addressed:

- **Reclosing out of Synchronism (3)**
- **Islanding (5)**
- **Equipment Overvoltage (6)**
- **Voltage Regulation Malfunction due to DR's (11)**
- **Cold Load Pick-up (14)**
- **Faults Within a DR Zone (15)**
- **Isolate DR for Upstream Fault (16)**
- **Fault Causes Voltage Dip – Trips DR (17)**
- **Loss of Exciter Causes Low Voltage (22)**
- **Inrush Of Induction Machines Causes Voltage Dips (23)**
- **Underfrequency (28)**

Protective Systems Required to Protect the Power System

Figure 18. consists of a large, self excited, induction generator connected to the primary, similar to the generator shown in Figure 8. The transformer is shown as being solidly grounded on the secondary instead of the primary.

Sufficient reactive support is assumed to be available to permit the induction generator to operate isolated from the utility source and maintain adequate voltage and frequency. Technical issues related to maintaining voltage and frequency with an isolated induction generator are discussed in the issues section of this document.

The protection systems listed in this section are required to protect the utility power system from disturbances caused by DR's, or from operating the DR's under abnormal conditions.

18.1.1 Dead Line Sensing (27I) (Covers Issue #3)

See Item 13.1.1.

18.1.2 Phase Undervoltage Relaying (27) (Covers Issues #5, 11, 14, 17, 22, & 23)

See Item 13.1.2.

18.1.3 Phase Overvoltage relaying(59I/T) (Covers Issues # 5, 6 & 11)

See Item 13.1.3.

18.1.4 Under/Over Frequency (81) (Covers Issues #5, and 28)

See Item 13.1.4.

18.1.5 Zero Sequence Overvoltage (59G) (Covers Issues #6 and 16)

See Item 13.1.5.

18.1.6 Breakers to be tripped by Undervoltage (27), Overvoltage (59I/T), Underfrequency (81), Zero Sequence Overvoltage (59G), relays

Minimally these relays must separate the utility's electrical system from the DR. This can be done by tripping breaker A, or B. If it is possible and desirable to maintain generation service to the local load, tripping breaker A may be sufficient.

18.1.7 Transformer High Side Overcurrent Relays (50/51)(50/51N) (Covers Issues #15 and 16)

See Item 1.1.7. This scheme also includes a neutral relay (50/51N). The neutral relay must be set quite sensitive because of the minimal amount of zero sequence current that flows during grounds on ungrounded systems. A window type CT may be more desirable than the residual connection shown for the 50/51N. It senses line-to-ground faults on the high side of the transformer. Because the transformer will contribute current to line-to-ground faults on the utility system, consideration must be given to how the neutral relay is to be coordinated with other devices on the utility system.

Other Protection Systems

The remaining protection systems, shown in Figure 18., are typically used to protect the DR from faults and facilitate operating the DR system. However, they are not required for interconnection.

18.1.8 Transformer Differential Relays (87) (Covers Issue #15) Not Applicable

18.1.9 Transformer Neutral Ground Relays (51G), (151G)

See Item 13.1.9.

18.1.10 Transformer Secondary Overcurrent Relays (51) Not Applicable

18.1.11 Instantaneous Overvoltage to Prevent Closing (159I)

Because this generator is self excited, this relay may be desirable to prevent closing of breaker A out of synchronism with the generator. See Item 13.1.11 for comparison to synchronous generator.

18.1.12 Synchronizing Relay (25)

Not required for an induction generator. See Item 13.1.12 for comparison to synchronous generator.

Minimum System Protection Technical Requirements for Interconnection to the Utility

18.2.1 Out-of-Synchronism Reclosing Protection

See Item 13.2.1.

18.2.2 Undervoltage Protection

See Item 13.2.2.

18.2.3* Overvoltage Protection

See Item 13.2.3.

18.2.4* Under and Over Frequency Protection

See Item 13.2.4.

18.2.5 Zero Sequence Overvoltage Protection

See Item 13.2.5.

18.2.6 Protection for Faults on the DR System

See Item 13.2.6.

18.2.7 Transfer Trip Scheme NOT REQUIRED

***Note:** Whenever the minimum utility circuit load is three times larger than the aggregated DR capacity, then some utilities waive the need for over frequency and overvoltage protection requirements.

Other Requirements

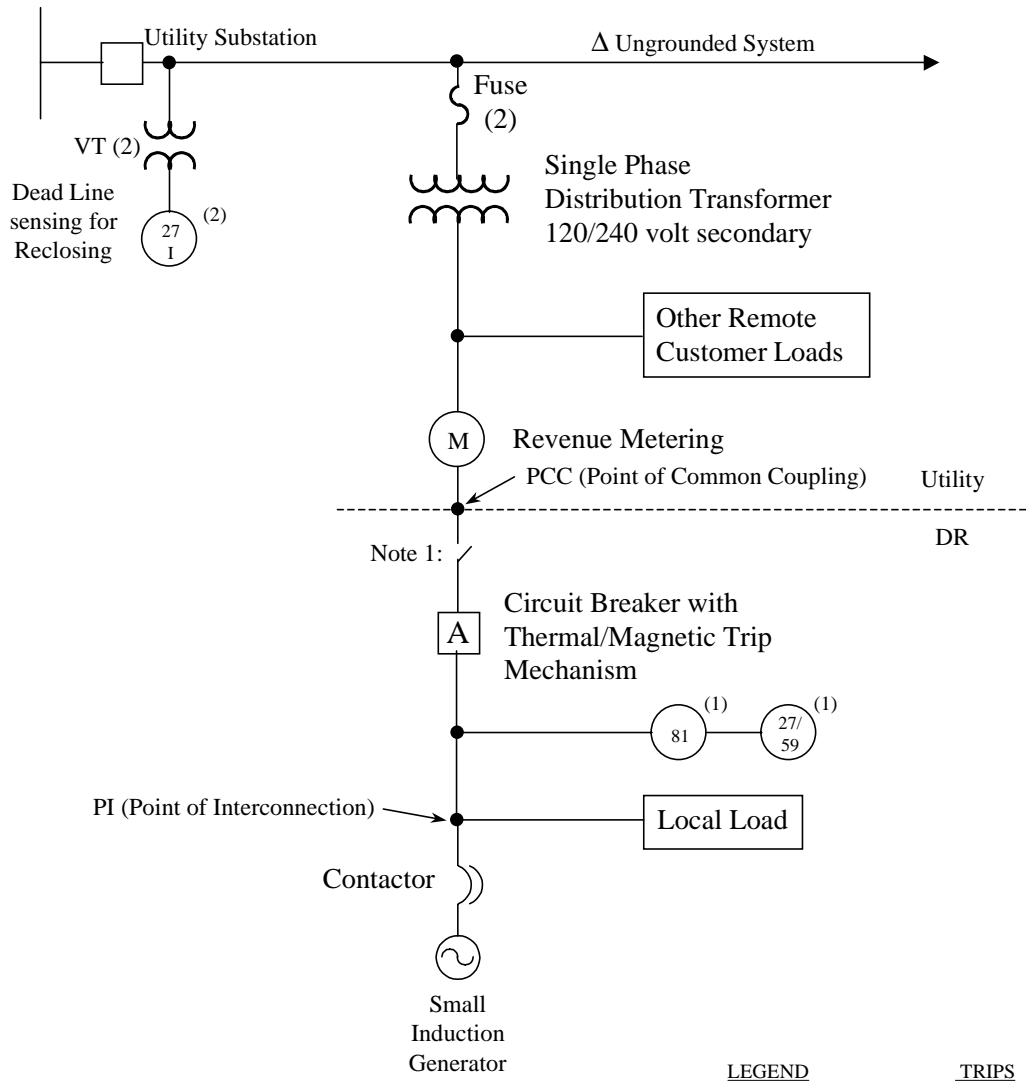
18.3.1 Accessible Lockable Disconnect

See Item 13.3.1.

18.3.2 Telemetry, Metering, Periodic Maintenance and Operating Agreements

See Item 13.3.2.

Figure 19. Small ($\leq 25\text{kVA}$) Single Phase Induction Generator



	<u>LEGEND</u>	<u>TRIPS</u>
	27/59 Time Under & Over voltage	A
	27I Instantaneous Undervoltage (Blocks Auto Reclose at Substation)	
	81 Overfrequency & Underfrequency	A

Note 1: Accessible and lockable disconnect switch.
 Note 2: The DR could partially serve other remote customer loads on the secondary system.
 Note 3: For loss of utility system, DR could continue to serve local load by opening breaker A. This presumes enough reactive is available for the induction generator.

Figure 19. Small ($\leq 25 \text{ kVA}$) Single Phase Induction Generator

Issues Addressed:

Reclosing out of Synchronism (3)
Islanding (5)
Faults Within a DR Zone (15)
Isolate DR for Upstream Fault (16)
Underfrequency (28)

Protective Systems Required to Protect the Power System

The protection systems listed in this section are required to protect the utility power system from disturbances caused by DR's, or from operating the DR's under abnormal conditions.

This DR can provide energy to other remote customer loads connected to the secondary system. The DR cannot run isolated from the utility and serve these loads, because there is no electrically operated isolation device and also, the DR requires reactive support from the utility to operate.

19.1.1 Dead Line Sensing (27I) (Covers Issue #3)

This would normally not be required for a DR of this size. The DR would be expected to be off-line prior to any time delayed reclosing operation. If an immediate reclosing is utilized, then dead line sensing might be considered. Even then it is unlikely the DR will be capable of sustaining a voltage detectable at the substation when isolated from the utility, because of its relatively small size compared to the circuit load.

19.1.2 Phase Undervoltage Relaying (27)

See Item 13.1.2.

19.1.3 Phase Overvoltage relaying(59) (Covers Issues #5, 6, and 11)

See Item 13.1.3.

19.1.4 Under/Over Frequency (81) (Covers Issues #5, and 28)

See Item 13.1.4.

19.1.5 Zero Sequence Overvoltage (59G) NOT REQUIRED

This scheme is not required due to the single phase connection of transformer.

19.1.6 Breakers to be tripped by Undervoltage (27), Overvoltage (59I/T), Underfrequency (81) relays

Breaker A is tripped by the 27/59, and 81 relays, because this is the only electrically operated device that can isolate the DR from the utility system.

19.1.7 Secondary Breaker Overcurrent Device (Covers Issue # 15 and 16)

Breaker A will isolate faults beyond the point of common coupling. The breaker's trip devices should also be set to coordinate with utility system protective devices and protective devices within the local load.

Other Protection Systems

No other protection systems are shown in Figure 19., because of the relatively simple configuration.

Minimum System Protection Technical Requirements for Interconnection to the Utility

19.2.1 Dead Line Sensing NOT REQUIRED

19.2.2 Undervoltage Protection

See Item 13.2.2.

19.2.3 Overvoltage Protection

See Item 13.2.3.

19.2.4 Under and Over Frequency Protection

See Item 13.2.4.

19.2.5 Zero Sequence Overvoltage NOT REQUIRED

19.2.6 Protection for Faults on the DR System

Breaker A provides the necessary isolation for faults beyond the point of common coupling to the DR.

19.2.7 Transfer Trip Scheme NOT REQUIRED

Other Requirements

19.3.1 Accessible Lockable Disconnect

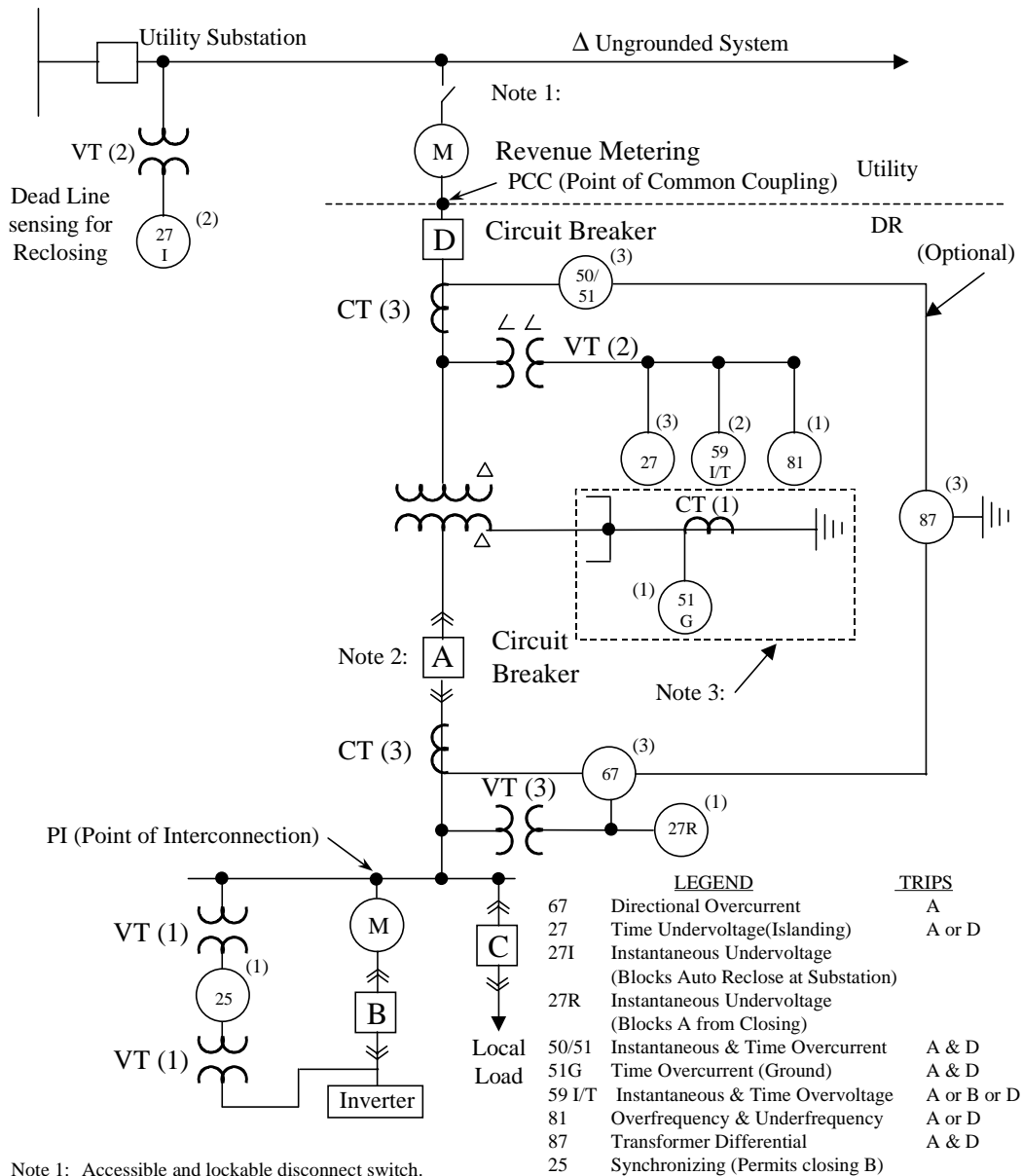
See Item 13.3.1.

19.3.2 Telemetry, Metering, Periodic Maintenance and Operating Agreements

Telemetry would normally not be done for such a small DR. However, local circumstances may dictate that some form of telemetry be installed.

See Item 13.3.2.

Detailed Discussion of System Protection Used in Figure 20. Large Three Phase Inverter (> 100kVA) and Delta – Delta Transformer with Differential Relay



Note 1: Accessible and lockable disconnect switch.

Note 2: For loss of utility system, DR could continue to serve local load by opening breaker A or breaker D.

Note 3: Omit for delta-delta, retain for delta-wye.

Note 4: For Delta- Wye transformations, there is ground fault current contribution for primary faults.
This transformer connection can be used for DR's operating isolated and serving other remote load connected line to line.

Figure 20. Large Inverter (> 100 kVA) and Delta - Delta or Delta - Wye Transformer with Differential Relay

Issues Addressed:

- **Reclosing out of Synchronism (3)**
- **Islanding (5)**
- **Equipment Overvoltage (6)**
- **Voltage Regulation Malfunction due to DR's (11)**
- **Cold Load Pick-up (14)**
- **Faults Within a DR Zone (15)**
- **Isolate DR for Upstream Fault (16)**
- **Fault Causes Voltage Dip – Trips DR (17)**
- **Loss of Exciter Causes Low Voltage (22)**
- **Inrush Of Induction Machines Causes Voltage Dips (23)**
- **Underfrequency (28)**

Protective Systems Required to Protect the Power System

The protection systems listed in this section are required to protect the utility power system from disturbances caused by DR's, or from operating the DR's under abnormal conditions. It is similar in requirements to Figure 13.

20.1.1 Dead Line Sensing (27I) (Covers Issue #3)

See Item 13.1.1.

20.1.2 Phase Undervoltage Relaying (27) (Covers Issues #5, 11, 14, 17, 22, & 23)

See Item 13.1.2.

20.1.3 Phase Overvoltage relaying (59I/T) (Covers Issues # 5, 6, & 11)

See Item 13.1.3.

20.1.4 Under/Over Frequency (81) (Covers Issues #5, and 28)

See Item 13.1.4.

20.1.5 Zero Sequence Overvoltage (59G) (Covers Issues #5, 6, and 16)

(Not Shown) See Item 13.1.5 and Figure 13.

10.1.6 Breakers to be tripped by Undervoltage (27), Overvoltage (59I/T), Underfrequency (81) relays

See Item 13.1.6.

20.1.7 Transformer High Side Overcurrent Relays 50/51 (Covers Issues #15 and 16)

This system provides protection for transformer internal faults and faults within the zone between breaker A and the transformer. If transformer differential relays (87) are used, the 50/51 relays are strictly backup protection for faults within the DR system. The 50/51 relays may trip for faults on the utility system, if the DR generation can contribute sufficient fault current and generation overcurrent protection at breaker B is not coordinated with the 50/51 relays to trip first. Also see Item 13.1.13.

Other Protection Systems

The remaining protection systems, shown in Figure 20., are typically used to protect the DR from faults and facilitate operating the DR system. However, they are not required for interconnection.

20.1.8 Transformer Differential Relays (87) (Covers Issue #15)

These relays sense faults within their zone of protection, that is, between the transformer high side CTs and the CTs on breaker A. They provide high speed clearing for faults on the transformer and all of the bus within the protected zone. These relays will normally trip breaker D and breaker A.

20.1.9 Transformer Neutral Ground Relay (51G) (Covers Issue #15)

This relay is not needed for an ungrounded delta configuration of the transformer. If the transformer is connected in a grounded wye, then this relay is normally installed.

20.1.10 Transformer Secondary Overcurrent Relays (51) (Covers Issue #15)

These relays are not shown. Refer to Figure 13. for typical connection.

See Item 13.1.10 for operation.

20.1.11 Instantaneous Overvoltage to Prevent Closing (27R)

See Item 13.1.11.

20.1.12 Synchronizing Relay (25)

See Item 13.1.12.

20.1.13 Directional Overcurrent (67) (Covers Issues #15, and 16)

See Item 13.1.13.

Minimum System Protection Technical Requirements for Interconnection to the Utility

20.2.1 Out-of-Synchronism Reclosing Protection

See Item 13.2.1.

20.2.2 Undervoltage Protection

See Item 13.2.2.

20.2.3* Overvoltage Protection

See Item 13.2.3.

20.2.4* Under and Over Frequency Protection

See Item 13.2.4.

20.2.5 Zero Sequence Overvoltage

(Not Shown) See Item 13.2.5 and Figure 13.

20.2.6 Protection for Faults on the DR System

See Item 13.2.6.

20.2.7 Transfer Trip Scheme NOT REQUIRED

***Note:** Whenever the minimum utility circuit load is three times larger than the aggregated DR capacity, then some utilities waive the need for over frequency and overvoltage protection requirements.

Other Requirements

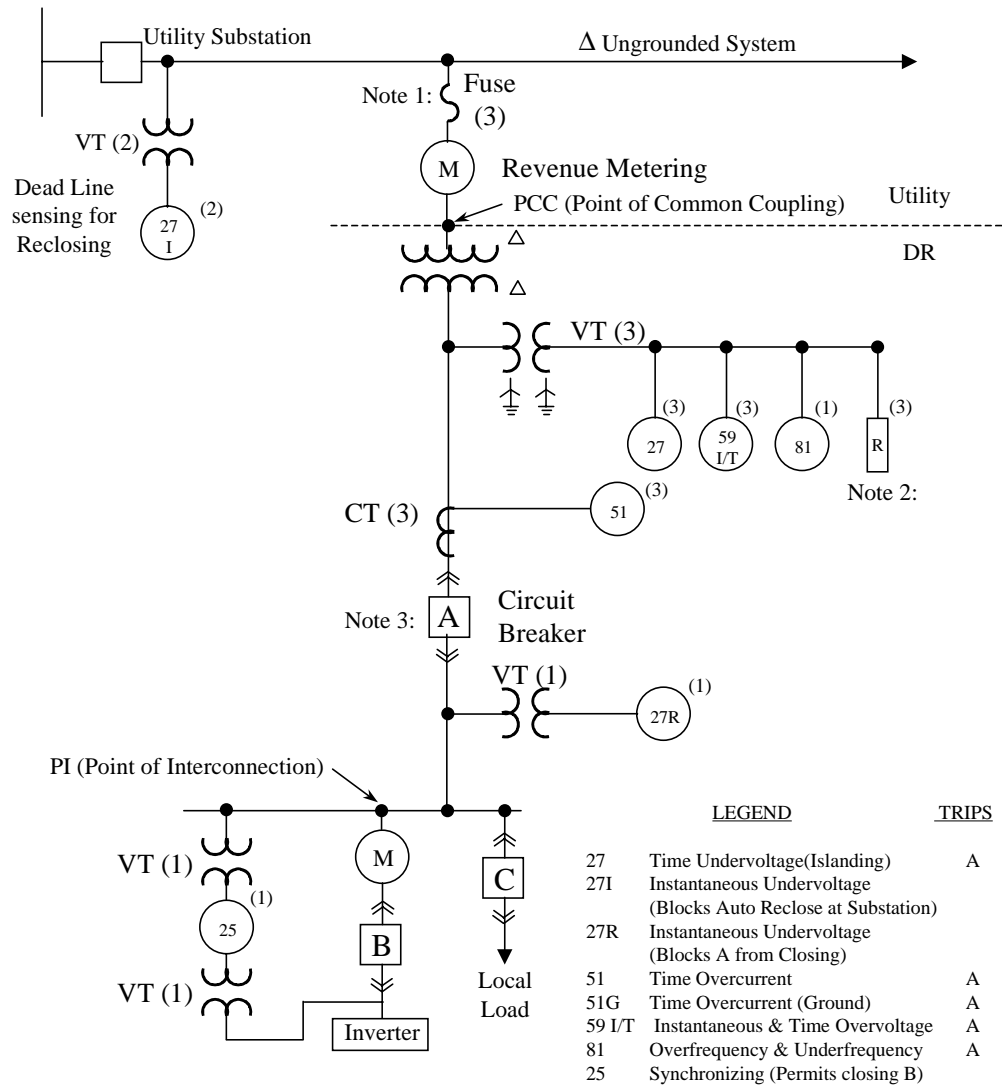
20.3.1 Accessible Lockable Disconnect

See Item 13.3.1.

20.3.2 Telemetry, Metering, Periodic Maintenance and Operating Agreements

See Item 13.3.2.

Detailed Discussion of System Protection Used in Figure 21. Small Three Phase Inverter ($\leq 100\text{kVA}$) and Delta – Delta Transformer



Note 1: Accessible and lockable fused disconnect switch.

Note 2: Ferroresonance suppression resistors.

Note 3: For loss of utility system, DR could continue to serve local load by opening breaker A.

Figure 21. Small Three Phase Inverter ($\leq 100\text{ kVA}$) Delta - Delta Transformer Protected by Fuses

Issues Addressed:

- **Reclosing out of Synchronism (3)**
- **Islanding (5)**
- **Equipment Overvoltage (6)**
- **Voltage Regulation Malfunction due to DR's (11)**
- **Cold Load Pick-up (14)**
- **Faults Within a DR Zone (15)**
- **Isolate DR for Upstream Fault (16)**
- **Fault Causes Voltage Dip – Trips DR (17)**
- **Loss of Exciter Causes Low Voltage (22)**
- **Inrush Of Induction Machines Causes Voltage Dips (23)**
- **Underfrequency (28)**

Protective Systems Required to Protect the Power System

The protection systems listed in this section are required to protect the utility power system from disturbances caused by DR's, or from operating the DR's under abnormal conditions.

Note that a set of surge suppression resistors has been installed due to the ungrounded delta secondary.

21.1.1 Dead Line Sensing (27I) (Covers Issue #3)

See Item 13.1.1.

21.1.2 Phase Undervoltage Relaying (27) (Covers Issues #5, 11, 14, 17, 22, & 23)

See Item 13.1.2.

21.1.3 Phase Overvoltage relaying (59I/T) (Covers Issues # 5, 6, & 11)

See Item 13.1.3.

21.1.4 Under/Over Frequency (81) (Covers Issues #5, and 28)

See Item 13.1.4

21.1.5 Zero Sequence Overvoltage (59G) (Covers Issues # 6, and 16)

Not shown. See Item 13.1.5 and Figure 13.

21.1.6 Breakers to be tripped by Undervoltage (27), Overvoltage (59I/T), Underfrequency (81) Zero Sequence Overvoltage (59G) relays

Minimally, these relays must separate the utility's electric system from the DR. This can be done by tripping breaker A, or B. If it is possible and desirable to maintain generation service to the local load, tripping breaker A may be sufficient.

21.1.7 Fuses (Covers Issues #15 and 16)

Fuses provide protection for transformer internal faults and faults on the high side of the transformer. Fuses also isolate the DR from faults on the utility system that are not cleared by other devices.

Other Protection Systems

The remaining protection systems, shown in Figure 21., are typically used to protect the DR from faults and facilitate operating the DR system. However, they are not required for interconnection.

21.1.8 Transformer Differential Relays (87) Not Applicable

21.1.9 Transformer Neutral Ground Relays (51G) (Covers Issue #1) Not Applicable

These relays are not needed due to the ungrounded delta configuration of the transformer.

21.1.10 Transformer Secondary Overcurrent Relays (51) (Covers Issue #15)

See Item 13.1.10.

21.1.11 Instantaneous Overvoltage to Prevent Closing (27R)

See Item 13.1.11

21.1.12 Synchronizing Relay (25)

See Item 13.1.12

Minimum System Protection Technical Requirements for Interconnection to the Utility

21.2.1 Out-of-Synchronism Reclosing Protection

See Item 13.2.1

21.2.2 Undervoltage Protection

See Item 13.2.2

21.2.3* Overvoltage Protection

See Item 13.2.3

21.2.4* Under and Over Frequency Protection

See Item 13.2.4.

21.2.5 Zero Sequence Overvoltage

See Item 13.2.5.

21.2.6 Protection for Faults on the DR System

See Item 13.2.6.

21.2.7 Transfer Trip Scheme NOT REQUIRED

***Note:** Whenever the minimum utility circuit load is three times larger than the aggregated DR capacity, then some utilities waive the need for over frequency and overvoltage protection requirements.

Other Requirements

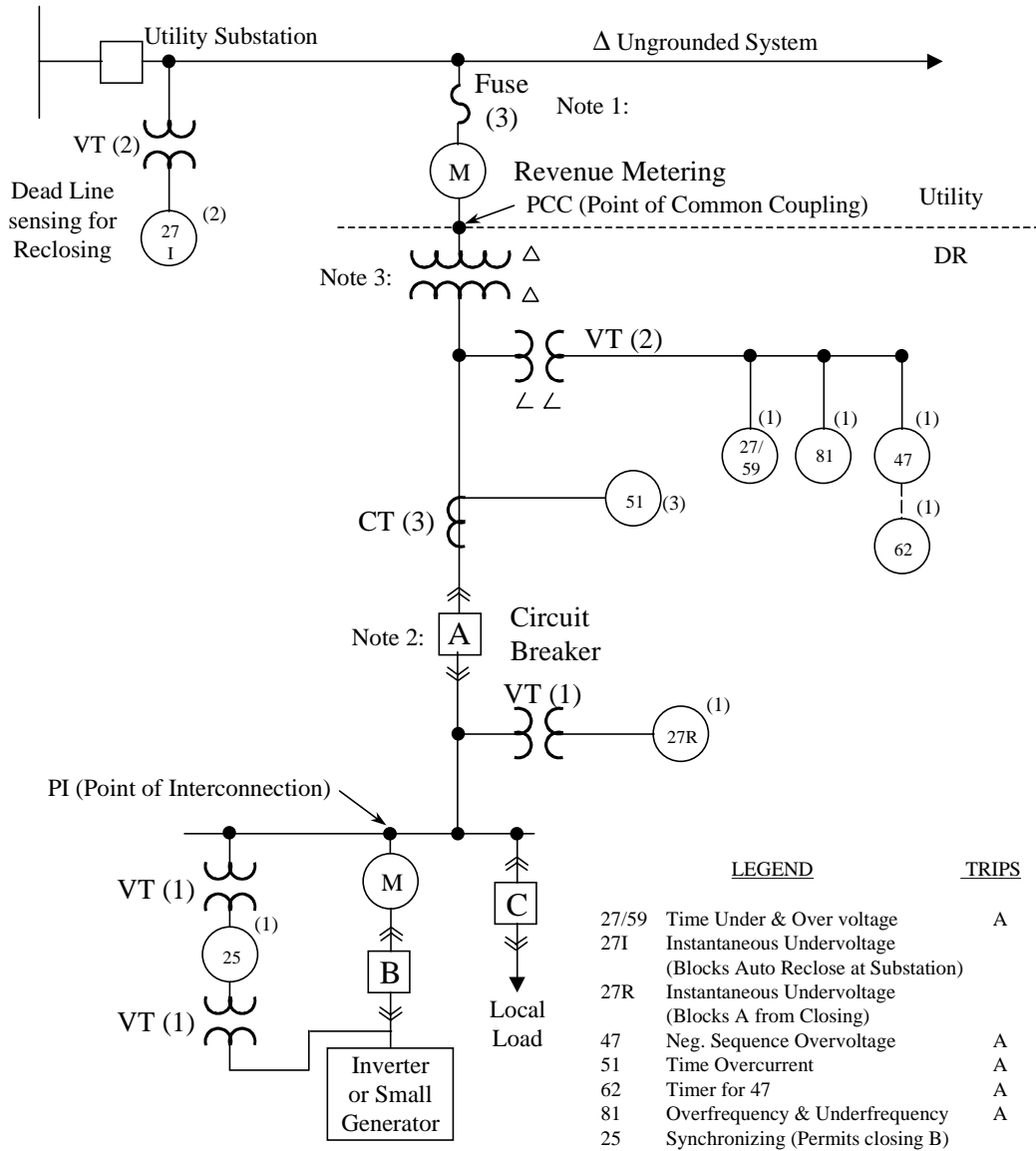
21.3.1 Accessible Lockable Disconnect

See Item 13.3.1.

21.3.2 Telemetry, Metering, Periodic Maintenance and Operating Agreements

See Item 13.3.2.

Detailed Discussion of System Protection Used in Figure 22. Small Three Phase Inverter ($\leq 100\text{kVA}$) or Generator Connected to Delta – Delta Transformer



Note 1: Accessible and lockable fused disconnect switch.

Note 2: For loss of utility system, DR could continue to serve local load by opening breaker A.

Note 3: For Delta - Delta transformations, there is no ground fault current contribution for primary faults.

This transformer connection can be used for DR's operating isolated and serving other remote line to line load.

Figure 22. Small Three Phase Inverter ($\leq 100\text{ kVA}$) or Generator ($\leq 100\text{ kVA}$) connected to Delta - Delta Transformer

Issues Addressed:

- **Reclosing out of Synchronism (3)**
- **Islanding (5)**
- **Equipment Overvoltage (6)**
- **Voltage Regulation Malfunction due to DR's (11)**
- **Cold Load Pick-up (14)**
- **Faults Within a DR Zone (15)**
- **Isolate DR for Upstream Fault (16)**
- **Fault Causes Voltage Dip – Trips DR (17)**
- **Loss of Exciter Causes Low Voltage (22)**
- **Inrush Of Induction Machines Causes Voltage Dips (23)**
- **Underfrequency (28)**

Protective Systems Required to Protect the Power System

The protection systems listed in this section are required to protect the utility power system from disturbances caused by DR's, or from operating the DR's under abnormal conditions.

This configuration is very similar to Figure 21. In this configuration the VTs are connected in an open delta and there are no surge suppression resistors. Negative sequence overvoltage protection has been utilized.

22.1.1 Dead Line Sensing (27I) (Covers Issue #3)

See Item 13.1.1.

22.1.2 Phase Undervoltage Relaying (27) (Covers Issues #5, 11, 14, 17, 22, & 23)

See Item 13.1.2.

22.1.3 Phase Overvoltage relaying (59) (Covers Issues # 5, 6, & 11)

See Item 13.1.3.

22.1.4 Under/Over Frequency (81) (Covers Issues #5, and 28)

See Item 13.1.4.

22.1.5 Zero Sequence Overvoltage (59G) (Covers Issues # 6, and 16)

(Not shown.) See Item 13.1.5 and Figure 13.

22.1.6 Breakers to be tripped by Undervoltage (27), Overvoltage (59I/T), Underfrequency (81) Zero Sequence Overvoltage (59G) relays

Minimally, these relays must separate the utility's electric system from the DR. This can be done by tripping breaker A, or B. If it is possible and desirable to maintain generation service to the local load, tripping breaker A may be sufficient.

22.1.7 Fuses (Covers Issues #15 and 16)

Fuses provide protection for transformer internal faults and faults on the high side of the transformer. Fuses also isolate the DR from faults on the utility system that are not cleared by other devices.

Other Protection Systems

The remaining protection systems, shown in Figure 22., are typically used to protect the DR from faults and facilitate operating the DR system. However, they are not required for interconnection.

22.1.8 Transformer Differential Relays (87) Not Applicable

22.1.9 Transformer Neutral Ground Relays (51G) (Covers Issue #1) Not Applicable

These relays are not needed due to the ungrounded delta configuration of the transformer.

22.1.10 Transformer Secondary Overcurrent Relays (51) (Covers Issue #15)

See Item 13.1.10.

22.1.11 Instantaneous Overvoltage to Prevent Closing (27R)

See Item 13.1.11.

22.1.12 Synchronizing Relay (25)

See Item 13.1.12.

22.1.13 Negative Sequence Overvoltage (47)

This relay detects an abnormally high level of unbalanced (negative sequence) voltage. It can detect single phase conditions caused by a blown fuse or open conductor.

Minimum System Protection Technical Requirements for Interconnection to the Utility

22.2.1 Out-of-Synchronism Reclosing Protection

See Item 13.2.1.

22.2.2 Undervoltage Protection

See Item 13.2.2.

22.2.3* Overvoltage Protection

See Item 13.2.3.

22.2.4* Under and Over Frequency Protection

See Item 13.2.4.

22.2.5 Zero Sequence Overvoltage

See Item 13.2.5.

22.2.6 Protection for Faults on the DR System

See Item 13.2.6.

22.2.7 Transfer Trip Scheme NOT REQUIRED

***Note:** Whenever the minimum utility circuit load is three times larger than the aggregated DR capacity, then some utilities waive the need for over frequency and overvoltage protection requirements.

Other Requirements

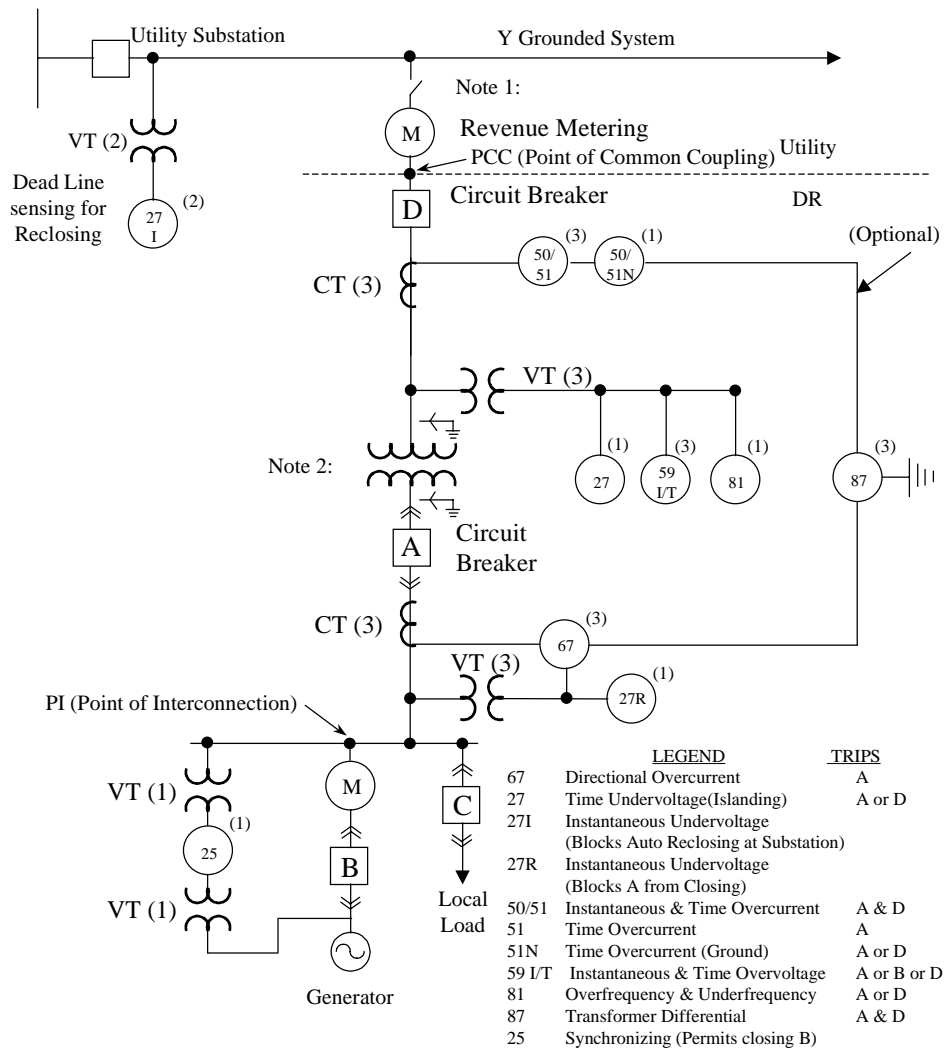
22.3.1 Accessible Lockable Disconnect

See Item 13.3.1.

22.3.2 Telemetry, Metering, Periodic Maintenance and Operating Agreements

See Item 13.3.2.

Detailed Discussion of System Protection Used in Figure 23. Large Synchronous Generator (1-5 MVA) Connected to the Primary and Serving Other Remote Isolated Loads



Note 1: Accessible and lockable disconnect switch.

Note 2: DR's using Wye-Wye transformations can run isolated and serve other remote loads.

Note 3: For loss of utility system, DR could continue to serve local load by opening breaker A or breaker D

Figure 23. Large Synchronous Generator (1 - 5 MVA) connected to the Primary and serving other isolated remote loads.

Issues Addressed:

- **Reclosing out of Synchronism (3)**
- **Islanding (5)**
- **Equipment Overvoltage (6)**
- **Voltage Regulation Malfunction due to DR's (11)**
- **Cold Load Pick-up (14)**
- **Faults Within a DR Zone (15)**
- **Isolate DR for Upstream Fault (16)**
- **Fault Causes Voltage Dip – Trips DR (17)**
- **Loss of Exciter Causes Low Voltage (22)**
- **Inrush Of Induction Machines Causes Voltage Dips (23)**
- **Underfrequency (28)**

Protective Systems Required to Protect the Power System

The protection systems listed in this section are required to protect the utility power system from disturbances caused by DR's, or from operating the DR's under abnormal conditions. This Figure is similar to Figure 4, however, it differs from Figure 4 in that the transformer is connected grounded wye – wye. The grounded wye primary permits the DR to serve load connected line-to-ground, while being isolated from the utility source.

This configuration has some issues worth reviewing. The grounded wye-wye transformer configuration is a ground current source for faults on the utility system and on the DR system. Coordination studies must take this into account. At present, some utilities will not ordinarily permit this connection, because of the “desensitizing” effect this ground source has on other ground relays at the substation. Also, consideration should be given to the relatively high level of ground fault current available from a solidly grounded wye-wye transformer. As a result, ground faults within the generator will typically result in more severe damage than with ungrounded or resistive grounded systems. Generator design, system design and economic analysis should take this into consideration.

The addition of neutral reactors or resistors in the generator neutral or transformer neutral to limit ground fault current will cause a neutral voltage shift during ground faults. Any unbalance in line to neutral load will experience a similar shift in voltage. This can result in low voltage on the phase with the highest load. Typically, load is not connected line to neutral on resistive or reactively grounded systems.

Also, note that this configuration does not have a 59G relay. It is not needed in this case, because the DR will be contributing current to any line-to-ground fault on the utility system. The DR in Figure 1. does not contribute ground fault current and requires the 59G relay to prevent sustained overvoltage after separation from the utility source.

23.1.1 Dead Line Sensing (27I) (Covers Issue #3)

See Item 1.1.1.

23.1.2 Phase Undervoltage Relaying (27) (Covers Issues #5, 11, 14, 17, 22, & 23)

See Item 1.1.2.

23.1.3 Phase Overvoltage relaying(59I/T) (Covers Issues # 5, 6 & 11)

See Item 1.1.3.

23.1.4 Under/Over Frequency (81) (Covers Issues #5, and 28)

See Item 1.1.4.

23.1.5 Zero Sequence Overvoltage (59G) (Covers Issues #5, 6, and 16) (NOT REQUIRED for this Figure)

This scheme is not required due to wye connected primary of transformer.

23.1.6 Breakers to be tripped by Undervoltage (27), Overvoltage (59I/T), Underfrequency (81) relays

See Item 1.1.6.

23.1.7 Transformer High Side Overcurrent Relays 50/51, 50/51N (Covers Issues #15 and 16)

This system provides protection for transformer internal faults and faults within the zone between breaker A and the transformer. If transformer differential relays (87) are used, the 50/51 relays are strictly backup protection for faults within the DR system. The 50/51 and/or 50/51N relays may trip for faults on the utility system, if the DR generation can contribute sufficient fault current and generation overcurrent protection at breaker B is not coordinated with the 50/51 relays to trip first. Also see Item 1.1.13.

Other Protection Systems

The remaining protection systems, shown in Figure 23., are typically used to protect the DR from faults and facilitate operating the DR system. However, they are not required for interconnection.

23.1.8 Transformer Differential Relays (87) (Covers Issue #15)

These relays sense faults within their zone of protection, that is, between the transformer high side CTs and the CTs on breaker A. They provide high speed clearing for faults on the transformer and all of the bus within the protected zone. These relays will normally trip breaker D and breaker A.

23.1.9 Transformer Neutral Ground Relays (51G), (151G) (NOT REQUIRED)

Ground relays fed from current transformers in the transformer ground connection are not normally needed for solidly grounded wye-wye transformers. These relays can be applied in addition to other relays that can sense ground faults to achieve a higher level of protective relay system reliability. In some cases, faster fault clearing can be achieved with 51G relays.

23.1.10 Transformer Secondary Overcurrent Relays (51) (Covers Issue #15)

These relays are not shown. Refer to Figure 1. for typical connection.

See Item 1.1.10 for operation.

23.1.11 Instantaneous Overvoltage to Prevent Closing (27R)

See Item 1.1.11.

23.1.12 Synchronizing Relay (25)

See Item 1.1.12.

23.1.13 Directional Overcurrent (67) (Covers Issues #15, and 16)

See Item 1.1.13.

Minimum System Protection Technical Requirements for Interconnection to the Utility

23.2.1 Out-of-Synchronism Reclosing Protection

See Item 1.2.1.

23.2.2 Undervoltage Protection

See Item 1.2.2.

23.2.3* Overvoltage Protection

See Item 1.2.3.

23.2.4* Under and Over Frequency Protection

See Item 1.2.4.

23.2.5 Zero Sequence Overvoltage is NOT REQUIRED

23.2.6 Protection for Faults on the DR System

See Item 1.2.6.

23.2.7 Transfer Trip Scheme NOT REQUIRED

***Note:** Whenever the minimum utility circuit load is three times larger than the aggregated DR capacity, then some utilities waive the need for over frequency and overvoltage protection requirements.

Other Requirements

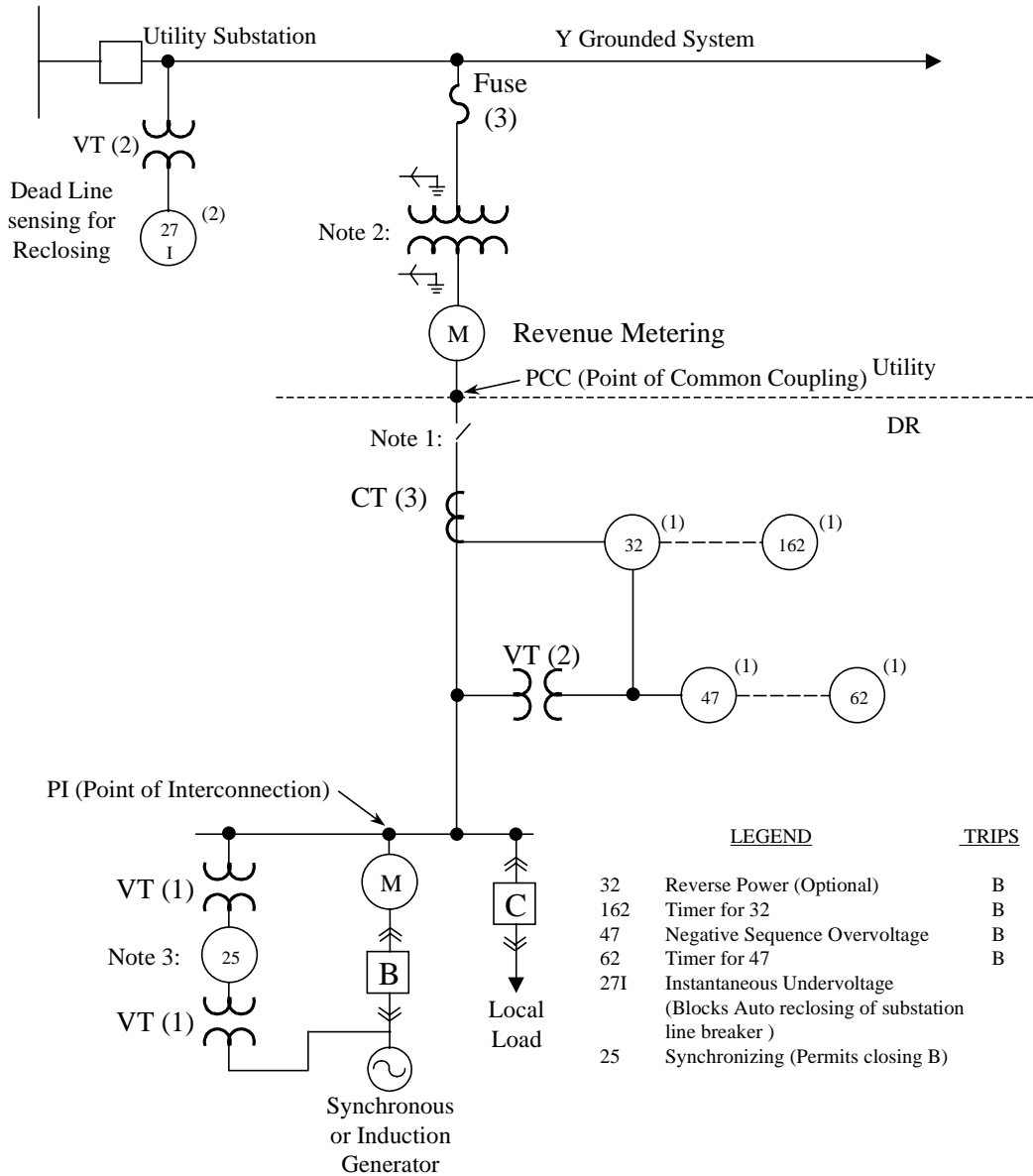
23.3.1 Accessible Lockable Disconnect

See Item 1.3.1.

23.3.2 Telemetry, Metering, Periodic Maintenance and Operating Agreements

See Item 1.3.2.

Figure 24. Small Synchronous or Induction Generator (10-100kVA) Connected to the Primary



Note 1: Alternate Location for Accessible and lockable disconnect switch.
 Note 2: Small DR's using Wye-Wye transformations can run isolated and serve other small remote loads.
 Note 3: The synchronizing relay 25 is needed for the synchronous generator only.

Figure 24. Small Synchronous (≤ 100 kVA) or Induction (≤ 100 kVA) Three-Phase Generator connected to Primary

Issues Addressed:

- **Reclosing out of Synchronism (3)**
- **Islanding (5)**
- **Faults Within a DR Zone (15)**
- **Isolate DR for Upstream Fault (16)**

Protective Systems Required to Protect the Power System

The protection systems listed in this section are required to protect the utility power system from disturbances caused by DR's, or from operating the DR's under abnormal conditions. Because this is a relatively small DR, and will have minimal effect on the operation of the utility system, a simplified protection system is employed. A reverse power relay is used to prevent power flow from the DR to the utility system.

This configuration has some issues worth reviewing. The grounded wye-wye transformer configuration is a ground current source for faults on the utility system and on the DR system. Coordination studies must take this into account. At present, some utilities will not ordinarily permit this connection, because of the "desensitizing" effect this ground source has on other ground relays at the substation. Also, consideration should be given to the relatively high level of ground fault current available from a solidly grounded wye-wye transformer. As a result, ground faults within the generator will typically result in more severe damage than with ungrounded or resistive grounded systems. Generator design, system design and economic analysis should take this into consideration.

The addition of neutral reactors or resistors in the generator neutral or transformer neutral to limit ground fault current will cause a neutral voltage shift during ground faults. Any unbalance in line to neutral load will experience a similar shift in voltage. This can result in low voltage on the phase with the highest load. Typically, load is not connected line to neutral on resistive or reactively grounded systems.

24.1.1 Dead Line Sensing (27I) (Covers Issue #3)

This would normally not be required for a DR of this size. The DR would be expected to be off-line prior to any time delayed reclosing operation. If an immediate reclosing is utilized, then dead line sensing might be considered. Even then it is unlikely the DR will be capable of sustaining a voltage detectable at the substation when isolated from the utility, because of its relatively small size compared to the circuit load.

24.1.2 Phase Undervoltage Relaying (27) NOT REQUIRED

24.1.3 Phase Overvoltage relaying(59I/T) Not Required

24.1.4 Under/Over Frequency (81) Not Required

24.1.5 Zero Sequence Overvoltage (59G) Not Required

24.1.6 Reverse Power Relay (32) (Covers Issue #5)

This device senses powerflow to the utility system and causes breaker B to trip. A timing relay is utilized to override the transient powerflow that occurs during system faults that are successfully isolated by other devices on the utility system.

24.1.7 Breakers to be tripped by 32 relay

Breaker B is required to be tripped by the 32 relay, since this is the only electrically operated device that can isolate the DR from the utility system.

24.1.8 Primary Fuses or Transformer High Side Overcurrent Relays 50/51, 50/51N (Covers Issues #15 and 16)

The primary fuses will isolate faults beyond the point of common coupling. They should also be selected to coordinate with utility system protective devices and downstream DR devices.

Other Protection Systems

The remaining protection systems, shown in Figure 24., are typically used to protect the DR from faults and facilitate operating the DR system. However, they are not required for interconnection.

24.1.9 Transformer Differential Relays (87) Not Applicable

24.1.10 Transformer Neutral Ground Relays (51G), (151G) Not Required

Ground relays fed from current transformers in the transformer ground connection are not normally needed for solidly grounded wye-wye transformers. These relays can be applied in addition to other relays that can sense ground faults to achieve a higher level of protective relay system reliability. In some cases, faster fault clearing can be achieved with 51G relays.

24.1.11 Transformer Secondary Overcurrent Relays (51) Not Applicable

24.1.12 Instantaneous Overvoltage to Prevent Closing (27R) Not Applicable

24.1.13 Synchronizing Relay (25)

See Item 1.1.12.

24.1.14 Negative Sequence Overvoltage (47)

This relay can detect blown fuses or dead phases on the primary of the transformer. It would be normally connected to trip breaker B. It may also be prudent to trip breaker C to protect the load from the sometimes damaging effects of single phasing.

Minimum System Protection Technical Requirements for Interconnection to the Utility

24.2.1 Reverse Power Protection

See Item 5.1.6.

24.2.2 Undervoltage Protection NOT REQUIRED

24.2.3 Overvoltage Protection NOT REQUIRED

24.2.4 Under and Over Frequency Protection NOT REQUIRED

24.2.5 Zero Sequence Overvoltage NOT REQUIRED

24.2.6 Protection for Faults on the DR System

Fuses provide the necessary isolation for faults beyond the point of common coupling to the DR.

24.2.7 Transfer Trip Scheme NOT REQUIRED

Other Requirements

24.3.1 Accessible Lockable Disconnect

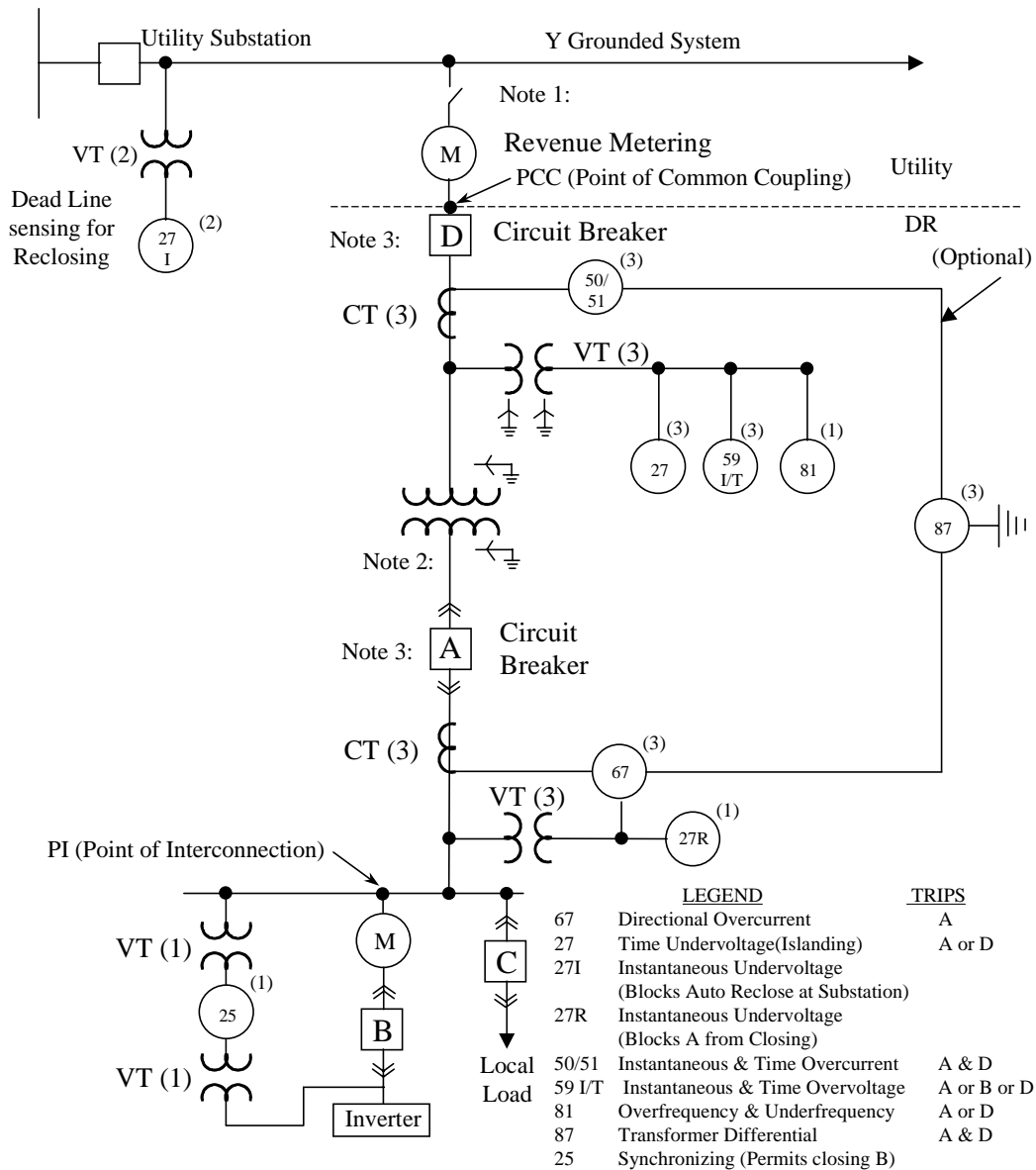
See Item 1.3.1.

24.3.2 Telemetry, Metering, Periodic Maintenance and Operating Agreements

Telemetry would normally not be done for such a small DR. However, local circumstances may dictate that some form of telemetry be installed.

See Item 1.3.2.

Detailed Discussion of System Protection Used in Figure 25. Large Three Phase Inverter (> 100kVA) and Grounded Wye – Wye Transformer with Differential Relay



Note 1: Accessible and lockable disconnect switch.

Note 2: DR's using Wye- Wye transformations can run isolated and serve other remote loads.

Note 3: For loss of utility system, DR could continue to serve local load by opening breaker A or breaker D.

Figure 25. Large Three Phase Inverter (> 100 kVA) and Grounded Wye - Wye Transformer with Differential Relay

Issues Addressed:

- **Reclosing out of Synchronism (3)**
- **Islanding (5)**
- **Equipment Overvoltage (6)**
- **Voltage Regulation Malfunction due to DR's (11)**
- **Cold Load Pick-up (14)**
- **Faults Within a DR Zone (15)**
- **Isolate DR for Upstream Fault (16)**
- **Fault Causes Voltage Dip – Trips DR (17)**
- **Loss of Exciter Causes Low Voltage (22)**
- **Inrush Of Induction Machines Causes Voltage Dips (23)**
- **Underfrequency (28)**

Protective Systems Required to Protect the Power System

The protection systems listed in this section are required to protect the utility power system from disturbances caused by DR's, or from operating the DR's under abnormal conditions. This Figure differs from Figures 1. and 3. in that the transformer is connected grounded wye – wye. The grounded wye primary permits the DR to serve load connected line-to-ground, while being isolated from the utility source.

This configuration has some issues worth reviewing. The grounded wye-wye transformer configuration is a ground current source. Coordination studies must take this into account. At present, some utilities will not ordinarily permit this connection, because of the “desensitizing” effect this ground source has on other ground relays at the substation. Also, consideration should be given to the relatively high level of ground fault current available from a solidly grounded wye-wye transformer. As a result, ground faults within the generator will typically result in more severe damage than with ungrounded or resistive grounded systems. Generator design, system design and economic analysis should take this into consideration.

The addition of neutral reactors or resistors in the generator neutral or transformer neutral to limit ground fault current will cause a neutral voltage shift during ground faults. Any unbalance in line to neutral load will experience a similar shift in voltage. This can result in low voltage on the phase with the highest load. Typically, load is not connected line to neutral on resistive or reactively grounded systems.

25.1.1 Dead Line Sensing (27I) (Covers Issue #3)

See Item 1.1.1.

25.1.2 Phase Undervoltage Relaying (27) (Covers Issues #5, 11, 14, 17, 22, & 23)

See Item 1.1.2.

25.1.3 Phase Overvoltage relaying (59I/T) (Covers Issues # 5, 6, & 11)

See Item 1.1.3.

25.1.4 Under/Over Frequency (81) (Covers Issues #5, and 28)

See Item 1.1.4.

25.1.5 Zero Sequence Overvoltage (59G) (Covers Issues #5, 6, and 16) (NOT REQUIRED for this Figure)

This scheme is not required due to wye connected primary of transformer.

25.1.6 Breakers to be tripped by Undervoltage (27), Overvoltage (59I/T), Underfrequency (81) relays

See Item 1.1.6.

25.1.7 Transformer High Side Overcurrent Relays 50/51, 51G (Covers Issues #15 and 16)

This system provides protection for transformer internal faults and faults within the zone between breaker A and the transformer. If transformer differential relays (87) are used, the 50/51 relays are strictly backup protection for faults within the DR system. The 50/51 and/or 51G relays may trip for faults on the utility system, if the DR generation can contribute sufficient fault current and generation overcurrent protection at breaker B is not coordinated with the 50/51 relays to trip first. Also see Item 1.1.13.

Other Protection Systems

The remaining protection systems, shown in Figure 25., are typically used to protect the DR from faults and facilitate operating the DR system. However, they are not required for interconnection.

25.1.8 Transformer Differential Relays (87) (Covers Issue #15)

These relays sense faults within their zone of protection, that is, between the transformer high side CTs and the CTs on breaker A. They provide high speed clearing for faults on the

transformer and all of the bus within the protected zone. Depending on relay setting, they may or may not sense ground faults due to limited current flowing through the reactor. These relays will normally trip breaker D and breaker A.

25.1.9 Transformer Neutral Ground Relays (51G) (Covers Issue #1)

Ground relays fed from current transformers in the transformer ground connection are not normally needed for solidly grounded wye-wye transformers. These relays can be applied in addition to other relays that can sense ground faults to achieve a higher level of protective relay system reliability. In some cases, faster fault clearing can be achieved with 51G relays.

25.1.10 Transformer Secondary Overcurrent Relays (51) (Covers Issue #15)

These relays are not shown. Refer to Figure 1. for typical connection.

See Item 1.1.10 for operation.

25.1.11 Instantaneous Overvoltage to Prevent Closing (27R)

See Item 1.1.11.

25.1.12 Synchronizing Relay (25)

See Item 1.1.12.

25.1.13 Directional Overcurrent (67) (Covers Issues #15, and 16)

See Item 1.1.13.

Minimum System Protection Technical Requirements for Interconnection to the Utility

25.2.1 Out-of-Synchronism Reclosing Protection

See Item 1.2.1.

25.2.2 Undervoltage Protection

See Item 1.2.2.

25.2.3* Overvoltage Protection

See Item 1.2.3.

25.2.4* Under and Over Frequency Protection

See Item 1.2.4.

25.2.5 Zero Sequence Overvoltage is NOT REQUIRED

25.2.6 Protection for Faults on the DR System

See Item 1.2.6.

25.2.7 Transfer Trip Scheme NOT REQUIRED

***Note:** Whenever the minimum utility circuit load is three times larger than the aggregated DR capacity, then some utilities waive the need for over frequency and overvoltage protection requirements.

Other Requirements

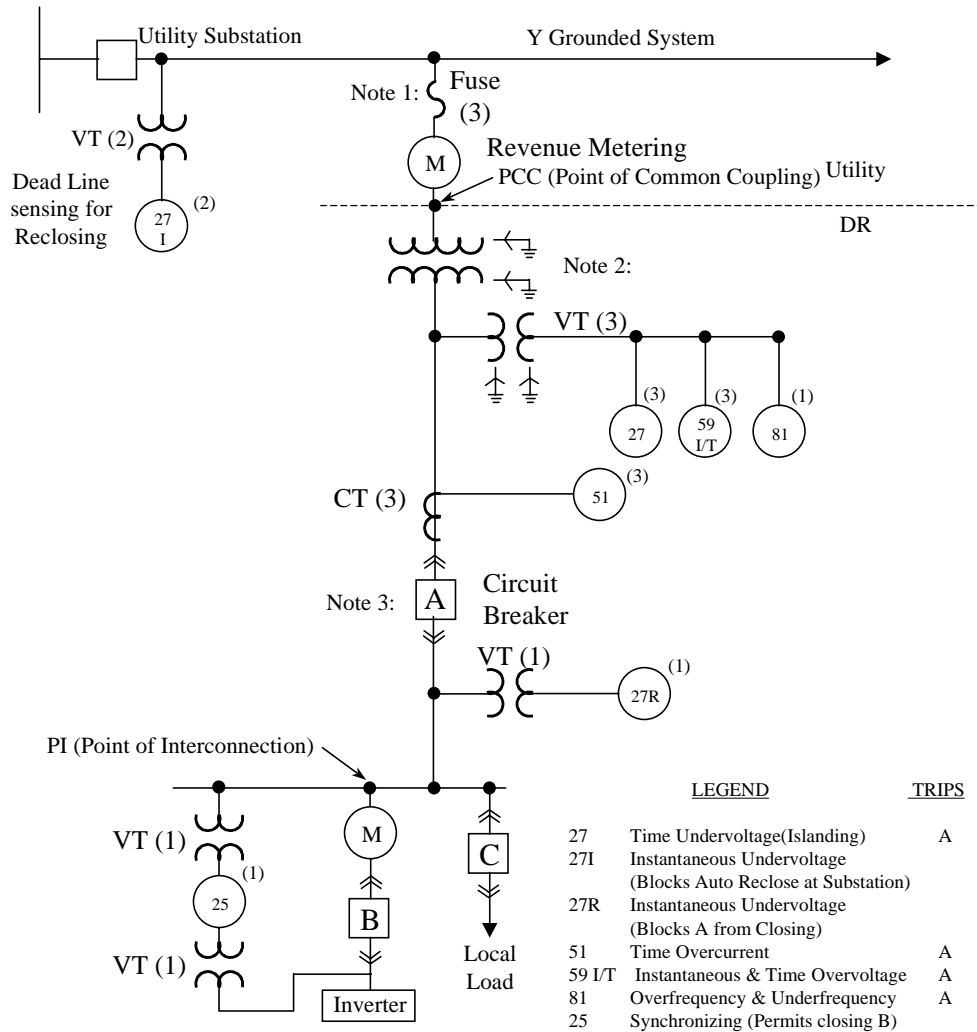
25.3.1 Accessible Lockable Disconnect

See Item 1.3.1.

25.3.2 Telemetry, Metering, Periodic Maintenance and Operating Agreements

See Item 1.3.2.

Detailed Discussion of System Protection Used in Figure 26. Small Three Phase Inverter ($\leq 100\text{kVA}$) and Grounded Wye – Wye Transformer



Note 1: Accessible and lockable fused disconnect switch.

Note 2: DR's using Wye- Wye transformations can run isolated and serve other remote loads.

Note 3: For loss of utility system, DR could continue to serve local load by opening breaker A.

Figure 26. Small Three Phase Inverter ($\leq 100\text{ kVA}$) Grounded Wye - Wye Transformer Protected by Fuses

Issues Addressed:

- **Reclosing out of Synchronism (3)**
- **Islanding (5)**
- **Equipment Overvoltage (6)**
- **Voltage Regulation Malfunction due to DR's (11)**
- **Cold Load Pick-up (14)**
- **Faults Within a DR Zone (15)**
- **Isolate DR for Upstream Fault (16)**
- **Fault Causes Voltage Dip – Trips DR (17)**
- **Loss of Exciter Causes Low Voltage (22)**
- **Inrush Of Induction Machines Causes Voltage Dips (23)**
- **Underfrequency (28)**

Protective Systems Required to Protect the Power System

The protection systems listed in this section are required to protect the utility power system from disturbances caused by DR's, or from operating the DR's under abnormal conditions. This Figure differs from Figures 1. and 3. in that the transformer is connected grounded wye – wye. The grounded wye primary permits the DR to serve load connected line-to-ground, while being isolated from the utility source.

This configuration has some issues worth reviewing. The grounded wye-delta transformer configuration becomes a ground current source. Coordination studies must take this into account. At present, some utilities will not ordinarily permit this connection, because of the “desensitizing” effect this ground source has on other ground relays at the substation. Note that this configuration uses a solidly grounded wye-wye transformer. Consideration should be given to the relatively high level of ground fault current available from a solidly grounded wye-wye transformer. As a result, ground faults within the generator will typically result in more severe damage than with ungrounded or resistive grounded systems. Generator design, system design and economic analysis should take this into consideration.

The addition of neutral reactors or resistors in the generator neutral or transformer neutral to limit ground fault current will cause a neutral voltage shift during ground faults. Any unbalance in line to neutral load will experience a similar shift in voltage. This can result in low voltage on the phase with the highest load. Typically, load is not connected line to neutral on resistive or reactively grounded systems.

26.1.1 Dead Line Sensing (27I) (Covers Issue #3)

See Item 1.1.1.

26.1.2 Phase Undervoltage Relaying (27) (Covers Issues #5, 11, 14, 17, 22, & 23)

See Item 1.1.2.

26.1.3 Phase Overvoltage relaying (59I/T) (Covers Issues # 5, 6, & 11)

See Item 1.1.3.

26.1.4 Under/Over Frequency (81) (Covers Issues #5, and 28)

See Item 1.1.4.

26.1.5 Zero Sequence Overvoltage (59G) (Covers Issues #5, 6, and 16) (NOT REQUIRED for this Figure)

This scheme is not required due to wye connected primary of transformer.

26.1.6 Breakers to be tripped by Undervoltage (27), Overvoltage (59I/T), Underfrequency (81) relays

See Item 1.1.6.

26.1.7 Fuses, and Transformer High Side Overcurrent Relay 51G (Covers Issues #15 and 16)

This system provides protection for transformer internal faults and faults within the zone between breaker A and the transformer. The 51G relays may trip for faults on the utility system, if the DR generation can contribute sufficient fault current and generation overcurrent protection at breaker B is not coordinated with the 50/51 relays to trip first. Also see Item 1.1.13.

Other Protection Systems

The remaining protection systems, shown in Figure 26., are typically used to protect the DR from faults and facilitate operating the DR system. However, they are not required for interconnection.

26.1.8 Transformer Differential Relays (87) Not Applicable

26.1.9 Transformer Neutral Ground Relays (51G) (Covers Issue #1)

Ground relays fed from current transformers in the transformer ground connection are not normally needed for solidly grounded wye-wye transformers. These relays can be applied in addition to other relays that can sense ground faults to achieve a higher level of protective relay system reliability. In some cases, faster fault clearing can be achieved with 51G relays.

26.1.10 Transformer Secondary Overcurrent Relays (51) (Covers Issue #15)

See Item 1.1.10.

26.1.11 Instantaneous Overvoltage to Prevent Closing (27R)

See Item 1.1.11.

26.1.12 Synchronizing Relay (25)

See Item 1.1.12.

Minimum System Protection Technical Requirements for Interconnection to the Utility

26.2.1 Out-of-Synchronism Reclosing Protection

See Item 1.2.1.

26.2.2 Undervoltage Protection

See Item 1.2.2.

26.2.3* Overvoltage Protection

See Item 1.2.3.

26.2.4* Under and Over Frequency Protection

See Item 1.2.4.

26.2.5 Zero Sequence Overvoltage is NOT REQUIRED

26.2.6 Protection for Faults on the DR System

See Item 1.2.6.

26.2.7 Transfer Trip Scheme NOT REQUIRED

***Note:** Whenever the minimum utility circuit load is three times larger than the aggregated DR capacity, then some utilities waive the need for over frequency and overvoltage protection requirements.

Other Requirements

26.3.1 Accessible Lockable Disconnect

See Item 1.3.1.

26.3.2 Telemetry, Metering, Periodic Maintenance and Operating Agreements

See Item 1.3.2.

<u>Device</u>	<u>Function</u>
21	Distance relay. Backup for System and Generator zone phase faults
24	Volts/Hz. Protection for generator overexcitation
25	Synchronizing check relay
32	Reverse power relay, anti motoring protection
40	Loss of field protection
46	Generator negative sequence unbalance current protection
49	Stator thermal protection
51GN	Time overcurrent ground relay
47	Negative Sequence Overvoltage
51TN	Backup for ground faults
51V	Voltage controlled or voltage restrained time overcurrent relay (Backup for system and generator phase faults)
59	Overvoltage protection
59GN	Overvoltage relay. Generator stator ground fault protection
60	Voltage balance relay. Detection of blown voltage transformer fuses
61	Generator Interturn Relay
62B	Breaker failure timer
63	Transformer fault pressure relay
64F	Field ground fault protection
71	Transformer oil or gas level
78	Loss of synchronism protection
81	Frequency relay. Both underfrequency and overfrequency protection
86	Hand reset lockout auxiliary relay
87G	Differential relay. Generator primary phase fault protection
87N	Stator ground fault differential protection
87T	Differential relay. Primary protection for transformer
87U	Differential relay for overall generator and transformer protection

Figure 27. List of Device Numbers and their Functions