Distributed Generation Protection

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Protection and Control of Distributed Energy Resources

Chapter 3

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Choose yourself and new technologies

HUMAN CAPITAL
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Wrocław University of Technology

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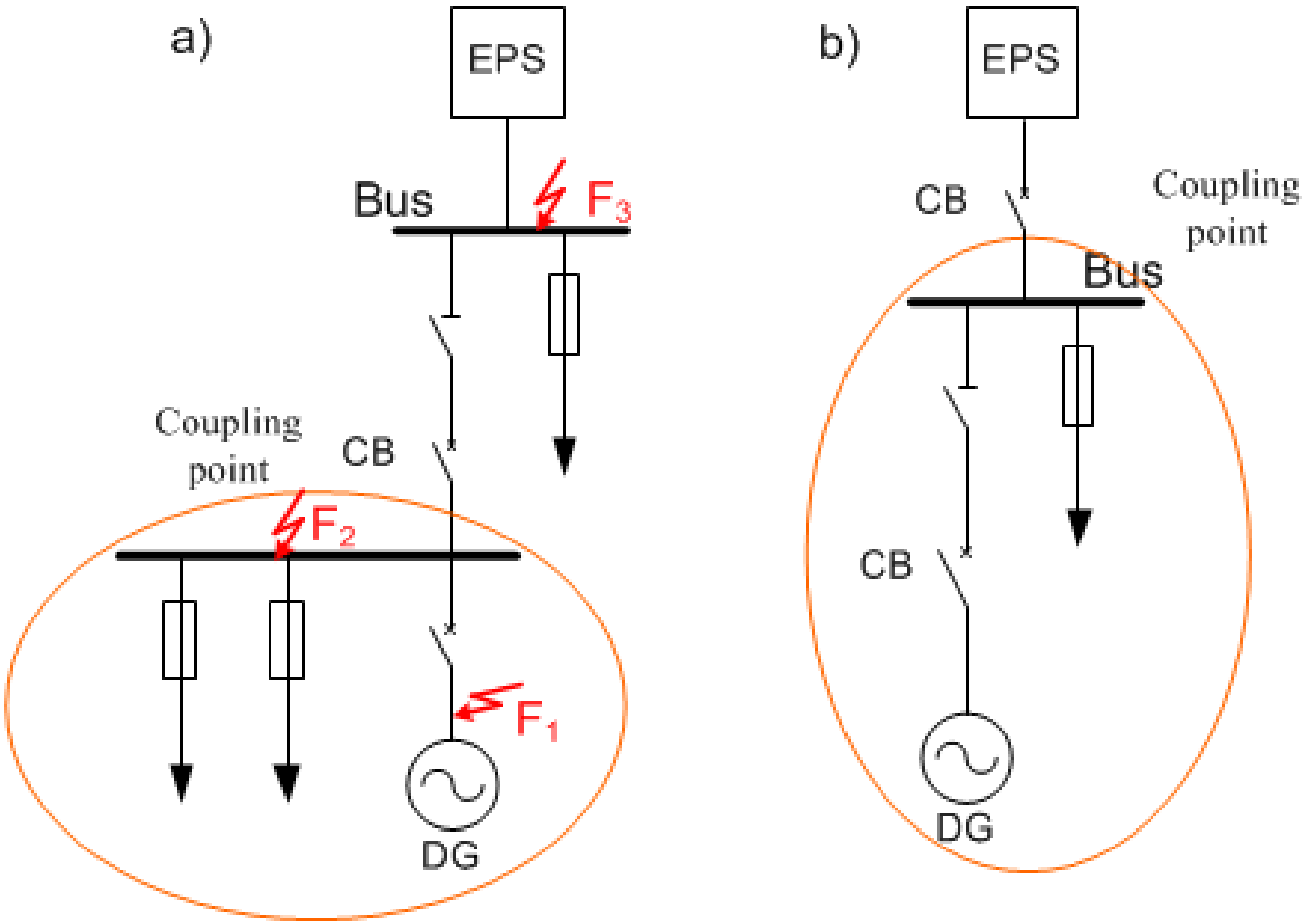
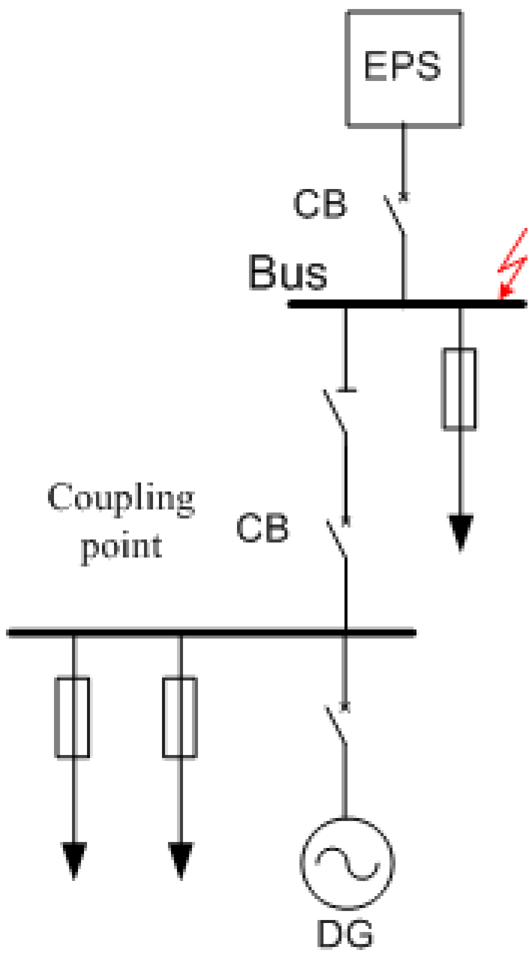
General Considerations

- **DG uses many forms of energy, such as wind, solar, biomass, hydroelectric, and fossil fuel energy.**
- **During major system disturbances and blackouts, DG can provide reliable on-site generation that keeps critical loads in service.**
- **Utilities typically prevent DG sources from feeding a disconnected section of the utility network after utility system outage what results in islanding condition.**

Islanding Condition



Islanding Condition



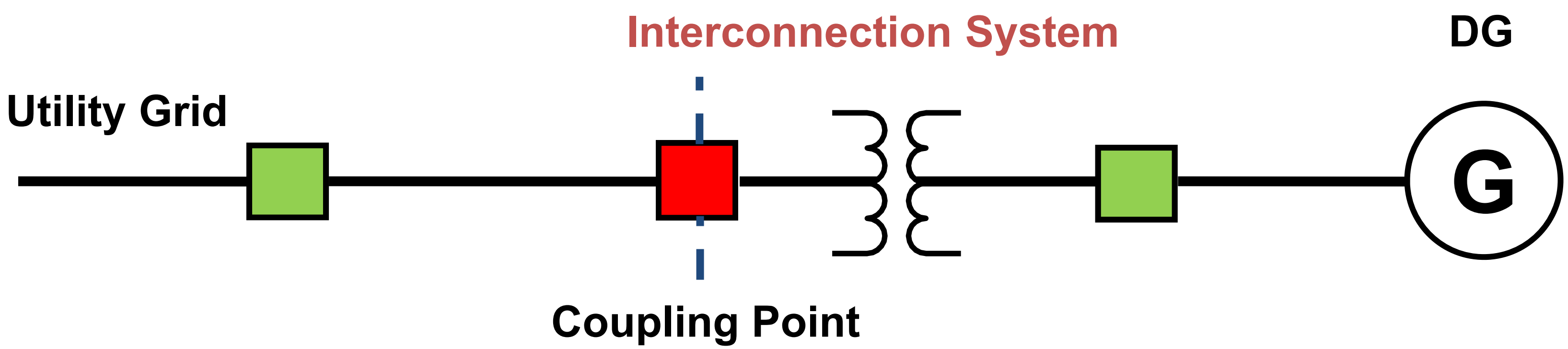
- When the utility breaker trips, the DG source may continue supporting fault current and may also cause overvoltage in the network.
- Without utility network working in parallel, the DG source may not satisfy quality standards and could damage customer equipment.
- Utility and DG equipment may suffer damage if an asynchronous breaker reclosure occurs.

Islanding Condition

- **The continuity of service may be assured even during islanding condition. As DG source control system improve, islanding operation will increasingly support continuity of service.**
- **Successful islanded operation requires adaptive load shedding to match DG to islanded load.**
- **Load shedding - cutting off the electric load on certain lines/areas when the demand becomes greater than the supply.**

Interconnection System

- **The interconnection system performs the functions necessary to maintain the safety, power quality, and reliability of connected EPSs and DGs.**
- **System complexity depends on the level of interaction required between the DG and the EPS.**
- **Interconnection is not a simple issue.**
- **Interconnection requirements are far from standard.**



General Requirements

- **Protection must be provided for DG installations to protect personnel, utility facilities, and equipment from the abnormal voltage and frequency that may occur when the DG is operating as an island.**
- **This protection must operate for short circuits, overloads, low or high voltage, and low or high frequency, and must prevent out-of-phase reclosing and energization of a dead supply line by the generator.**
- **The generator owner is responsible for the protection of his equipment, which is usually specified by his consultant or equipment manufacturer.**

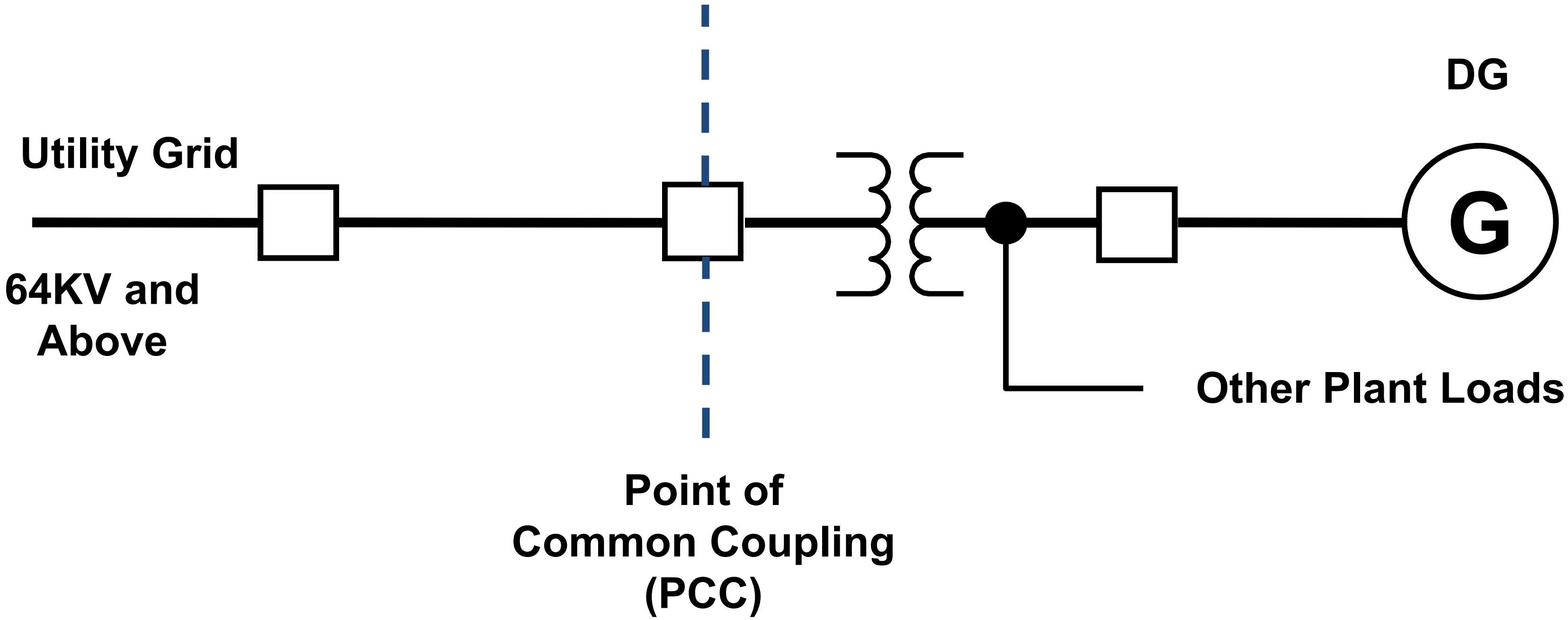
Intertie Protection

- **Recent interest in distributed generator installation into low voltage buses near electrical consumers, has created some new challenges for protection engineers that are different from traditional radially based protection methodologies.**
- **Therefore, typical protection configurations need to be re-thought such as re-closures, out-of-step monitoring, impedance relay protection zones with the detection of unplanned islanding of distributed generator systems.**

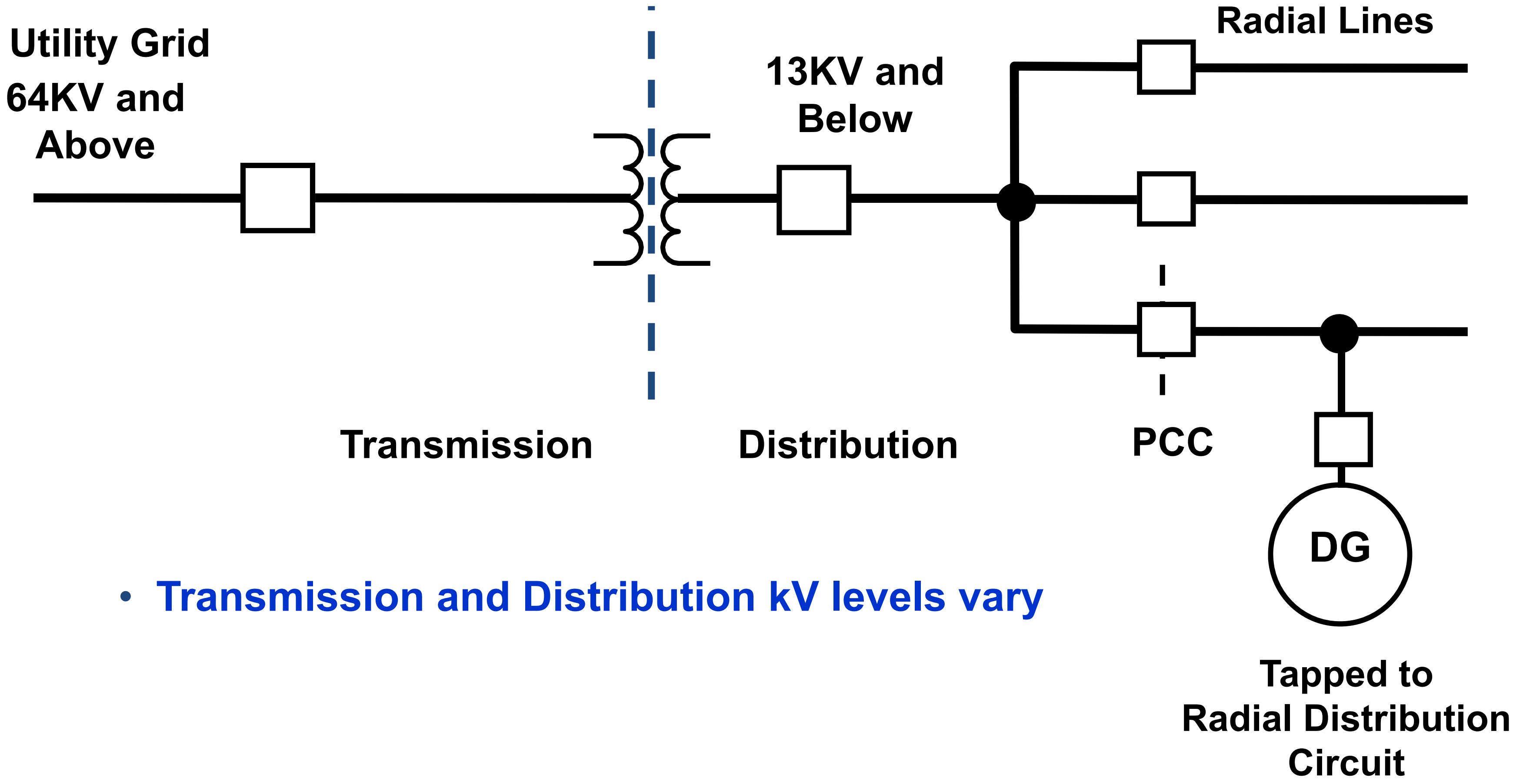
Intertie Protection

- **Intertie protection requirements are influenced by the size and characteristics of the DG, along with the characteristics of the associated utility supply system.**
- **Large generators with utility transmission tie points**
  - **10MVA or greater generators,**
  - **Usually dispatched directly with utility load dispatcher,**
  - **Relay protection and control as if it were part of the utility system connected to transmission grid.**
- **Generators with utility distribution tie points.**

Large Generator – Transmission Tie



Small Generator – Distribution Tie



- Transmission and Distribution kV levels vary

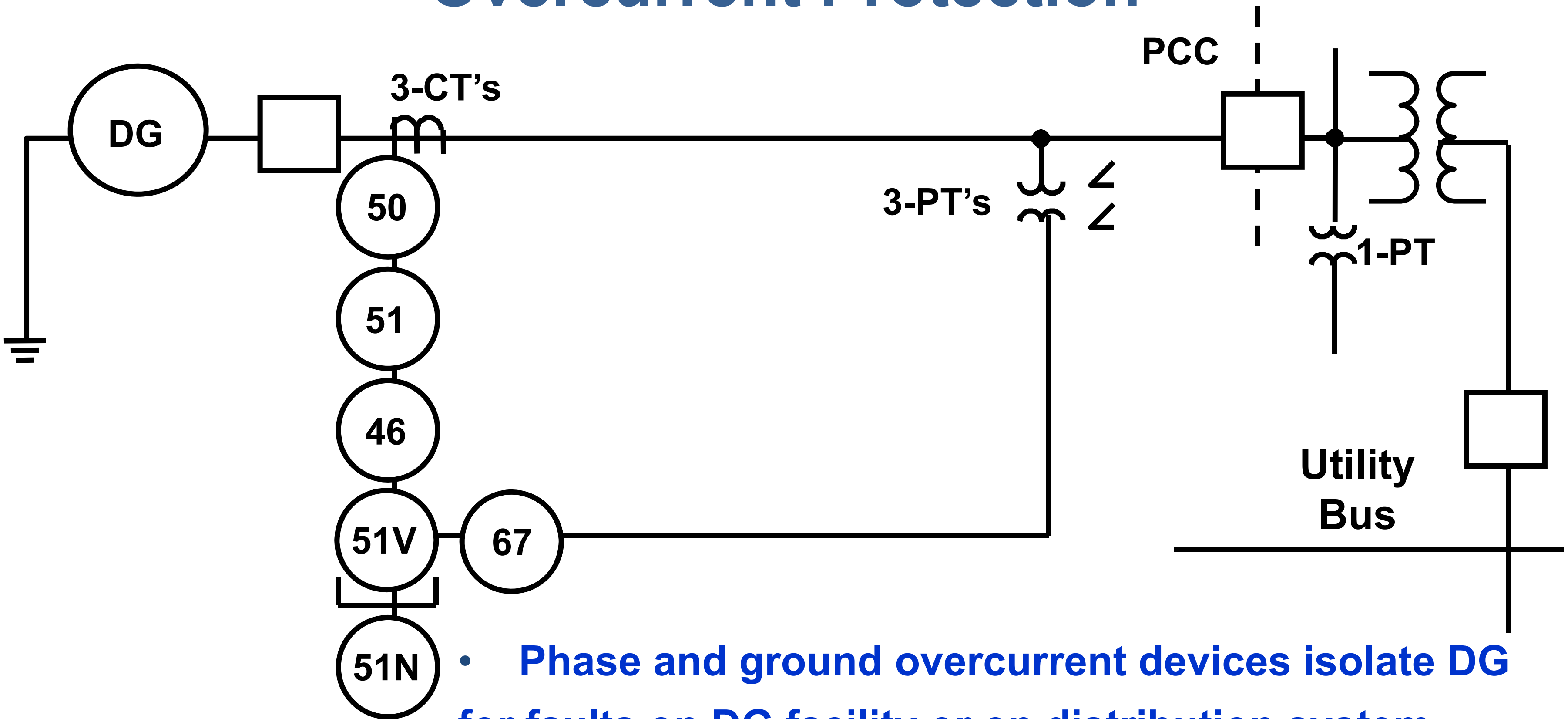
Typical Utility Operation Requirements

- **Maintain voltage ±10% approximately.**
- **Maintain frequency ±0.1Hz approximately.**
- **Power quality – Limits on voltage dips, sags, swells, flicker and harmonics.**
- **Minimize interference with communications equipment. Outage times should be minimized.**

Typical Utility Operation

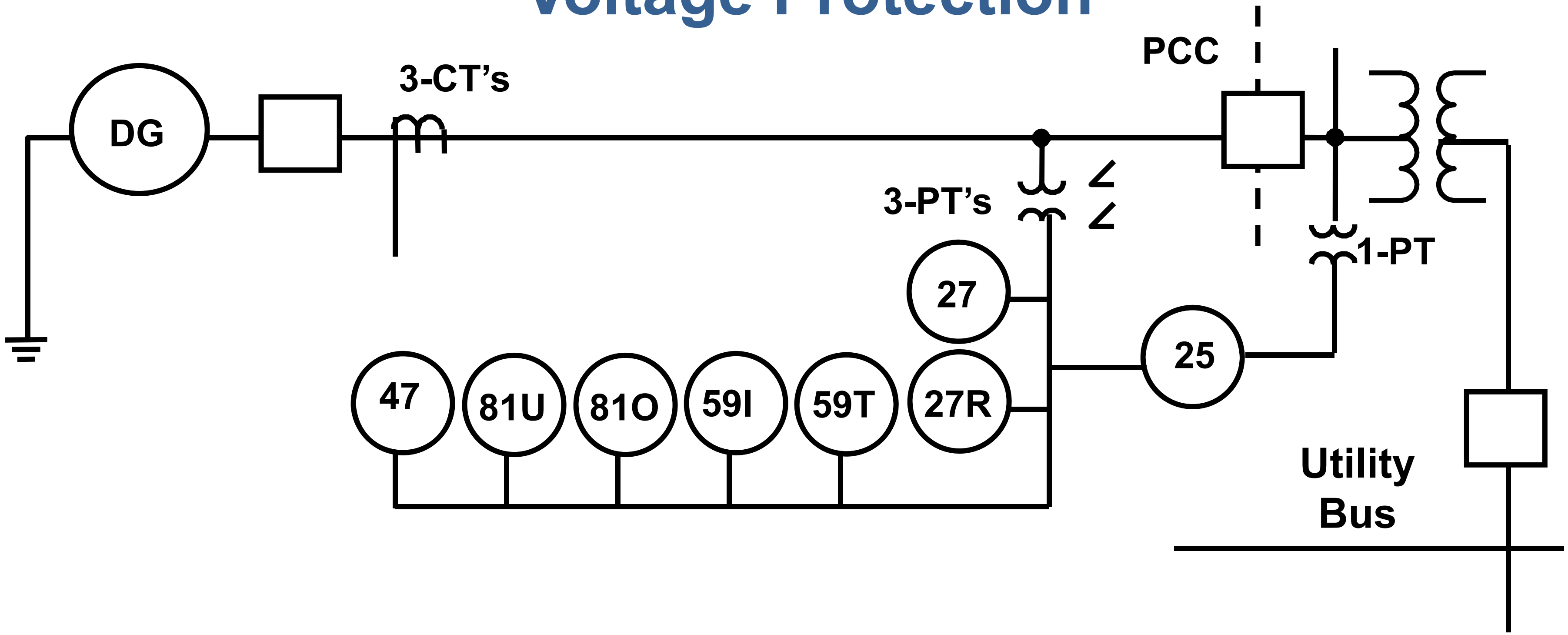
- **Fault detection and fault removal promptly to minimize damage to equipment and voltage distortions.**
- **Reclosing substation feeder breaker, as fast as 1/3 second, to minimize outage times.**
- **Provide safe, de-energized condition when dead line work is done or line is on the ground.**

Overcurrent Protection



- Phase and ground overcurrent devices isolate DG for faults on DG facility or on distribution system.
- 67/67N may be used for anti-islanding in place of 32.
- 51V may be optional to prevent nuisance 27 tripping.

Voltage Protection

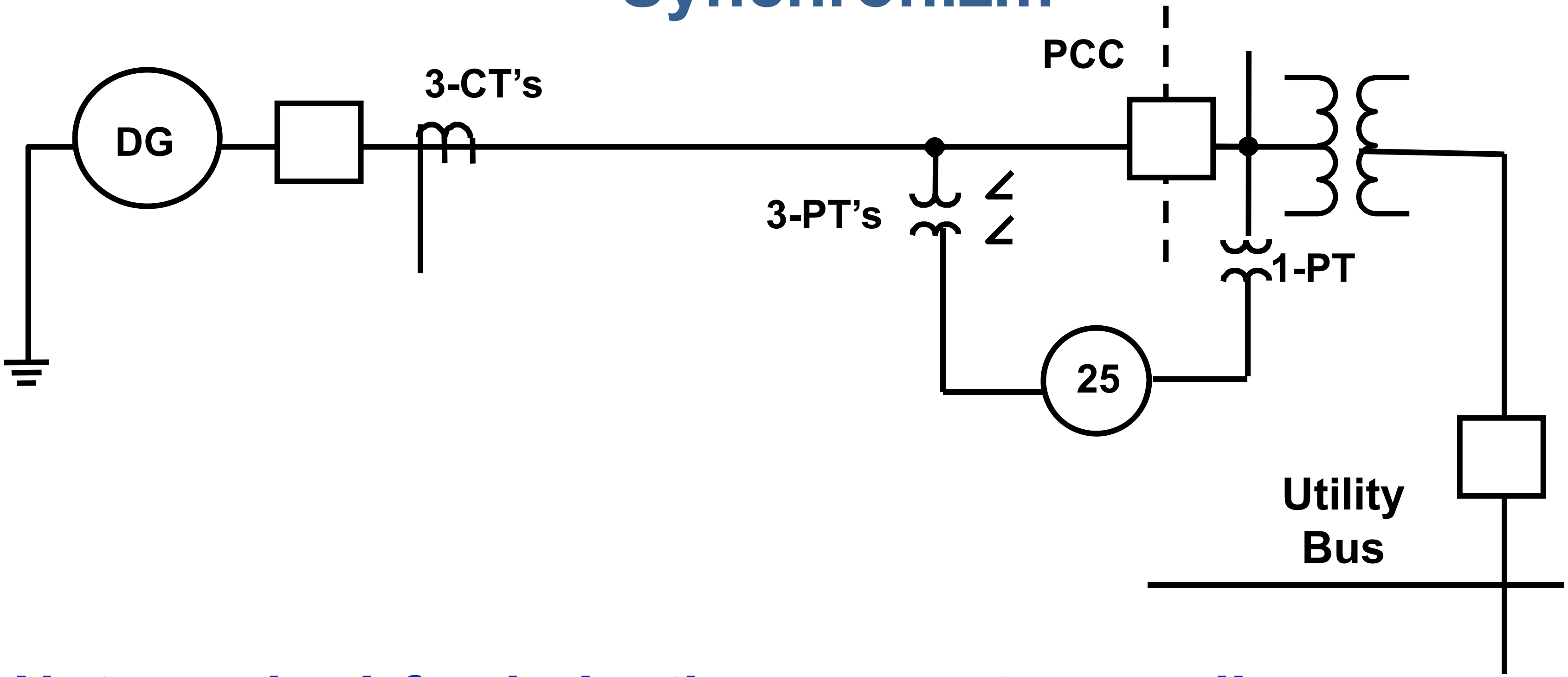


- UV and OV relays operate when voltage outside predetermines levels and within predetermined times.
- UV relays have time delay to prevent unnecessary trips for external faults (may include inst 27R for very low levels)...

Voltage Protection

- **UV and OV relays operate when voltage outside predetermines levels and within predetermined times.**
- **UV relays have time delay to prevent unnecessary trips for external faults (may include inst 27R for very low levels).**
- **OV relays may include inst 59I for ferroresonance.**
- **UF and OF relay levels operate when frequency outside predetermined levels and within predetermined times.**
- **67/67N may be used for anti-islanding in place of 32.**
- **51V may be optional to prevent nuisance 27 tripping.**

Synchronizm

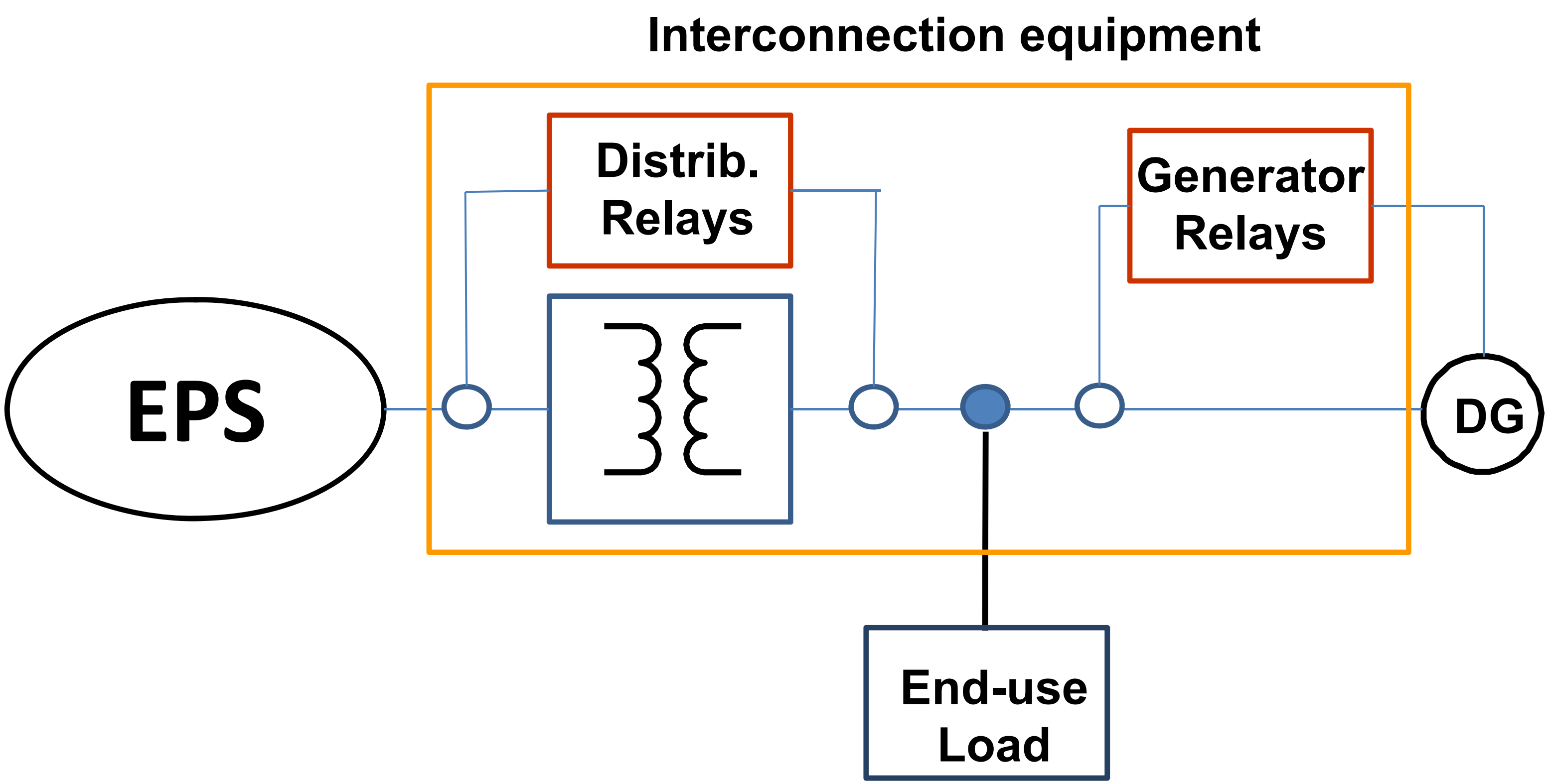


- Not required for induction generators or line commutated inverters.
- Utility cannot synch to DG.
- DG must not energize utility when utility is deenergized.

Intertie Protection

- **Manufacturers of Protective and Control Relays. This is the most conventional and experienced source for the control of DG protection. The protective relay industry has supported the protection of transmission, distribution, and generation of electricity for many years.**
- **The relays are the main controlling elements of interconnection.**
- **For large DG systems connected at the transmission level, the relaying design for interconnection is likely integrated into and coordinated with the existing design of transmission protection.**

Intertie Protection

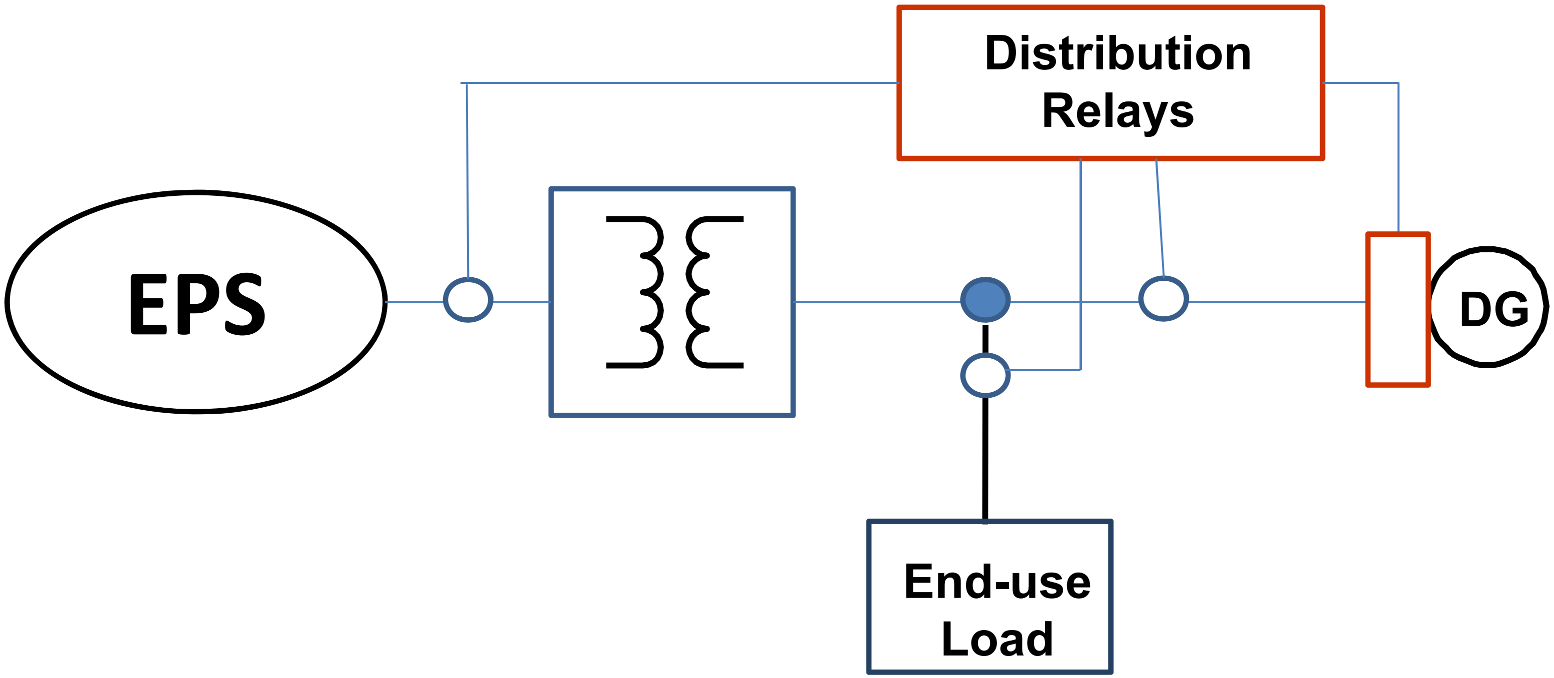


Conventional Independent Relaying Packages for Utility Feeder and Non-Utility Generators

Intertie Protection

- **The distribution-feeder relay package and the generator-protection relay package can be provided by the traditional protective relay industry.**
- **Paralleling control and transfer from utility to generator source may also be offered in this integrated package.**
- **This can add functionality while simplifying installation and reducing the overall cost of interconnection.**

Intertie Protection

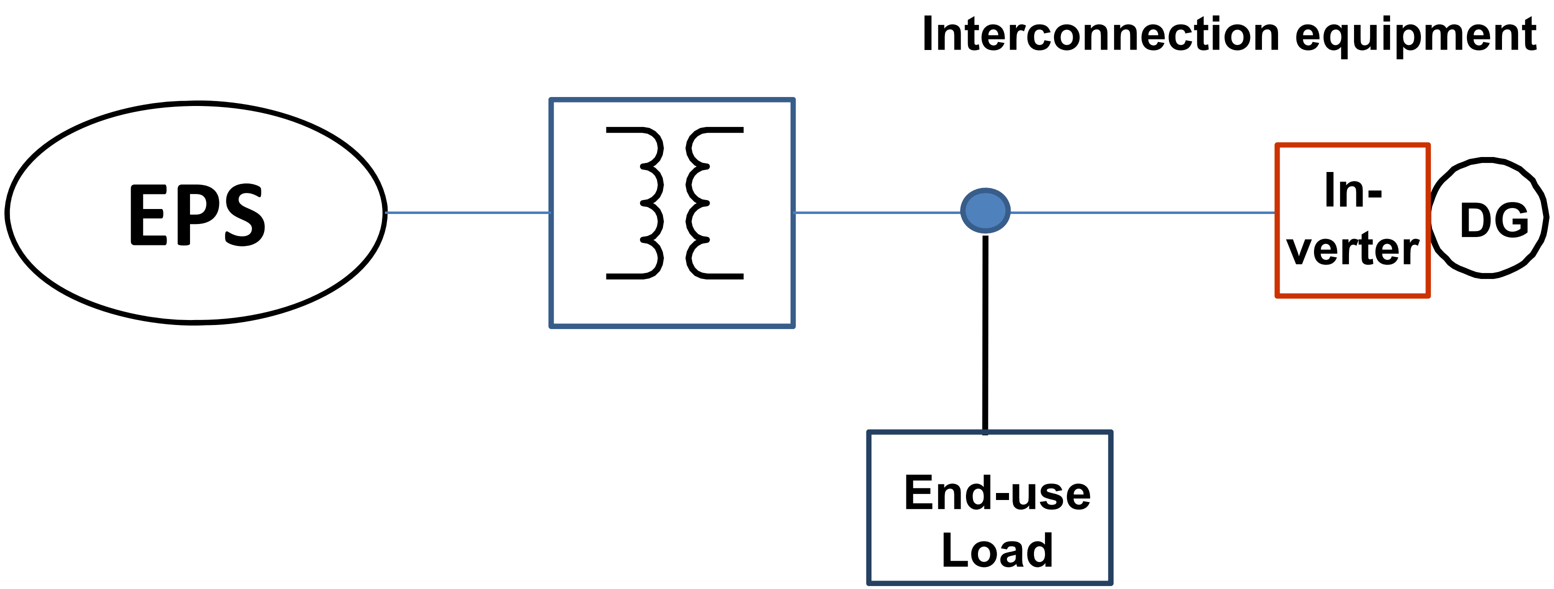


Integrated Distribution Feeder and Generator Protection in One Package

Intertie Protection – DG with Electronic Inverter

- **In the case of smaller distributed generators that are interconnected via an electronic inverter, the control capability of the inverter will play a role in making the connection. In this case, the customer-side protective functions can be completely addressed in the inverter.**
- **Depending on inverter size and design, a transformer may not be required between the generator inverter and the local facility power system. If the inverter connection can be made without a transformer and without additional synchronization and relaying protection, significant savings in the interconnection costs can be realized.**

Intertie Protection

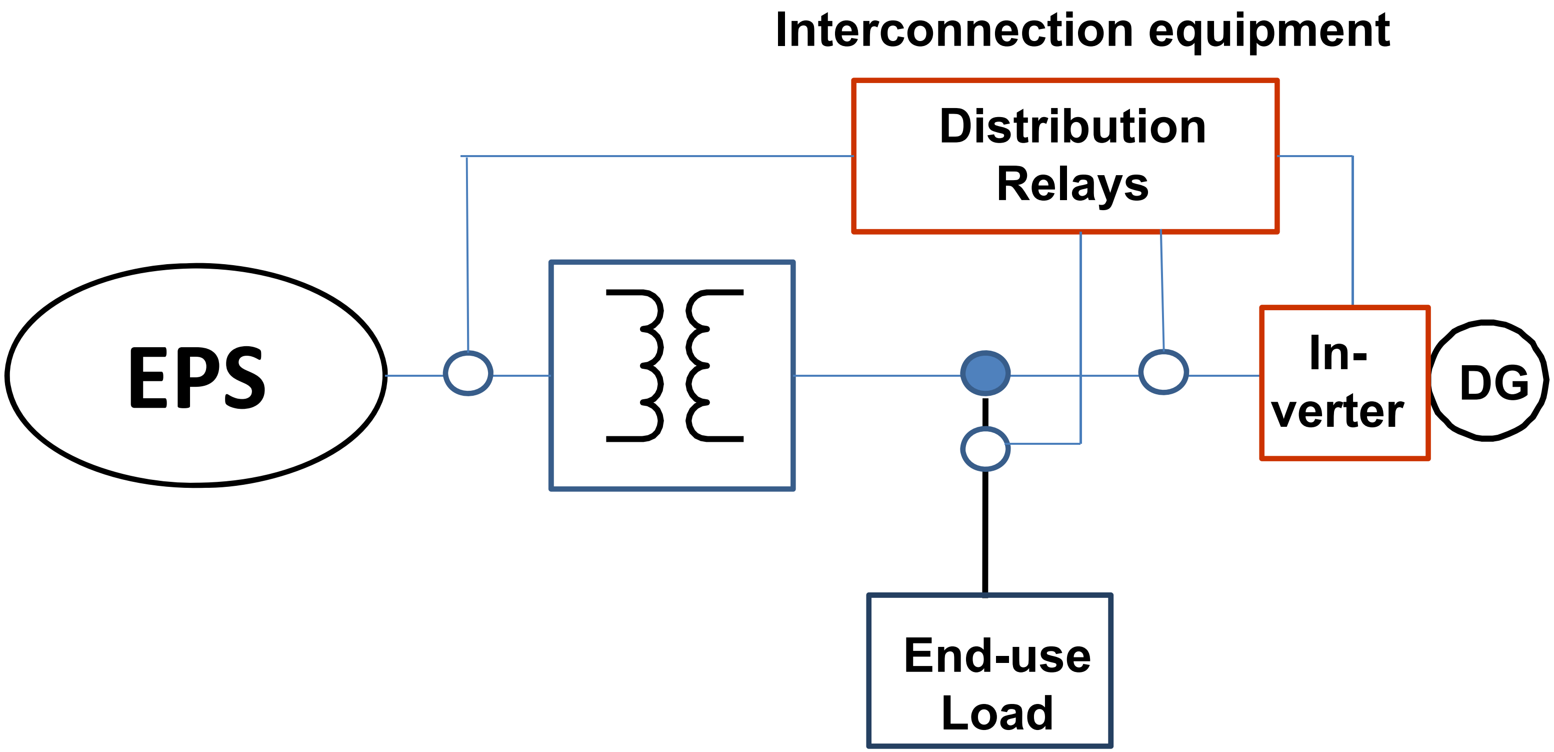


Interconnection Functions Provided by Electronic Inverter and Transformer

Intertie Protection – DG with Electronic Inverter

- **If the inverter-connected DG is large compared to the locally connected load, additional transformer isolation and additional relaying will likely be required.**
- **The protection is a hybrid between integrated inverter and separate conventional relaying.**
- **In this case, a step-up isolation transformer is likely to be required for both the load and the DG.**

Intertie Protection



Protection for a Large DG Inverter May Require for both Built-In and Conventional Relay Functions

DG - EPS Grid Interconnection Options

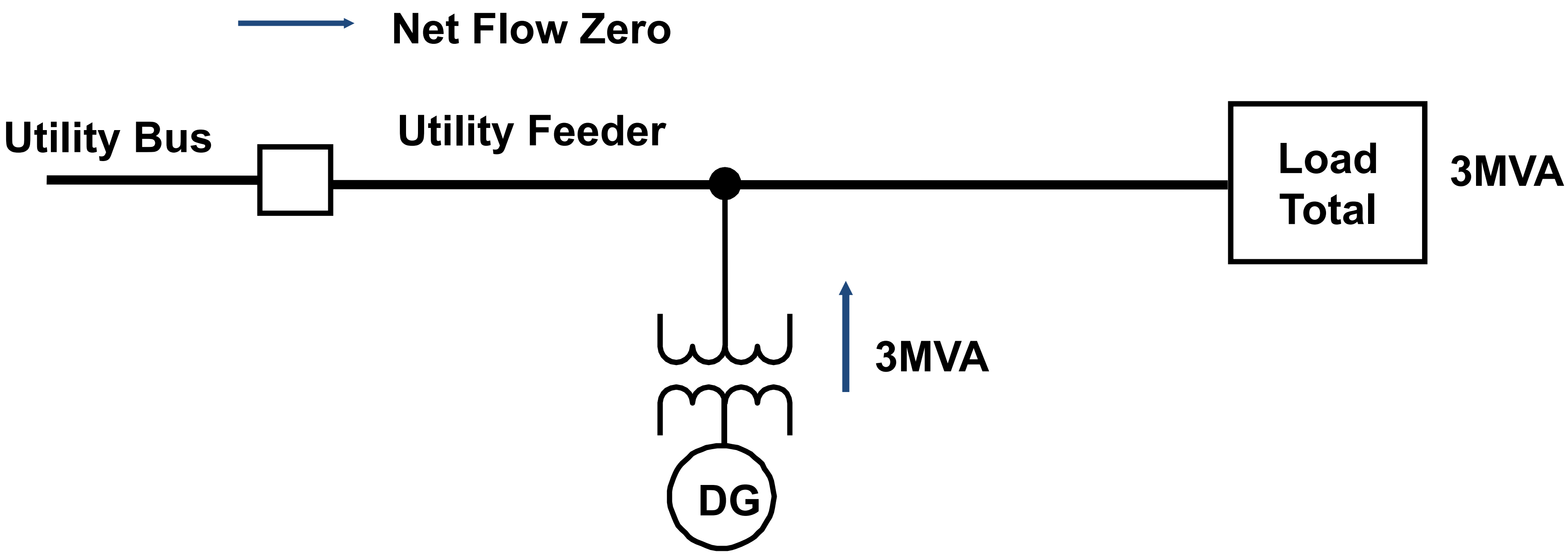
- No Interconnection - Complete Isolated Operation.
- Isolated DG - Automatic Transfer to EPS.
- Parallel DG Operation - No Power Export.
- Parallel DG Operation with Power Export.

Anti-islanding Problem

The condition of islanding, defined as
when a section of the non utility generation system is isolated from the main utility system,
is often considered undesirable because of:

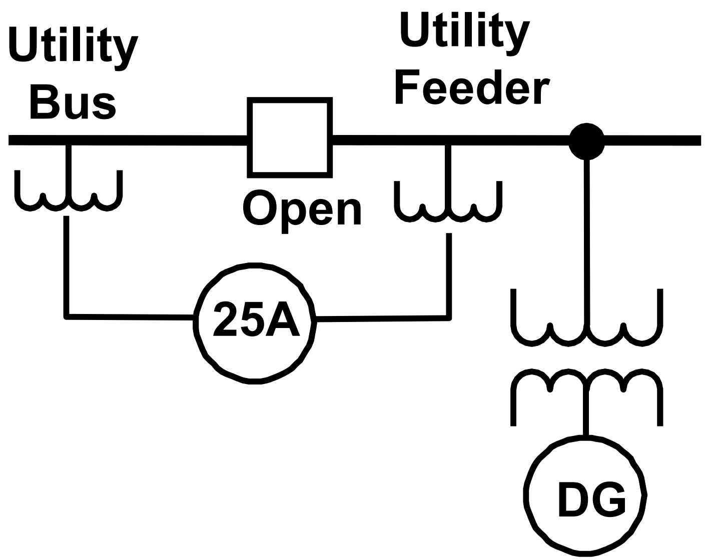
- **the potential damage to existing equipment,**
- **utility liability concerns,**
- **reduction of power reliability and**
- **power quality.**

Anti-islanding Problem



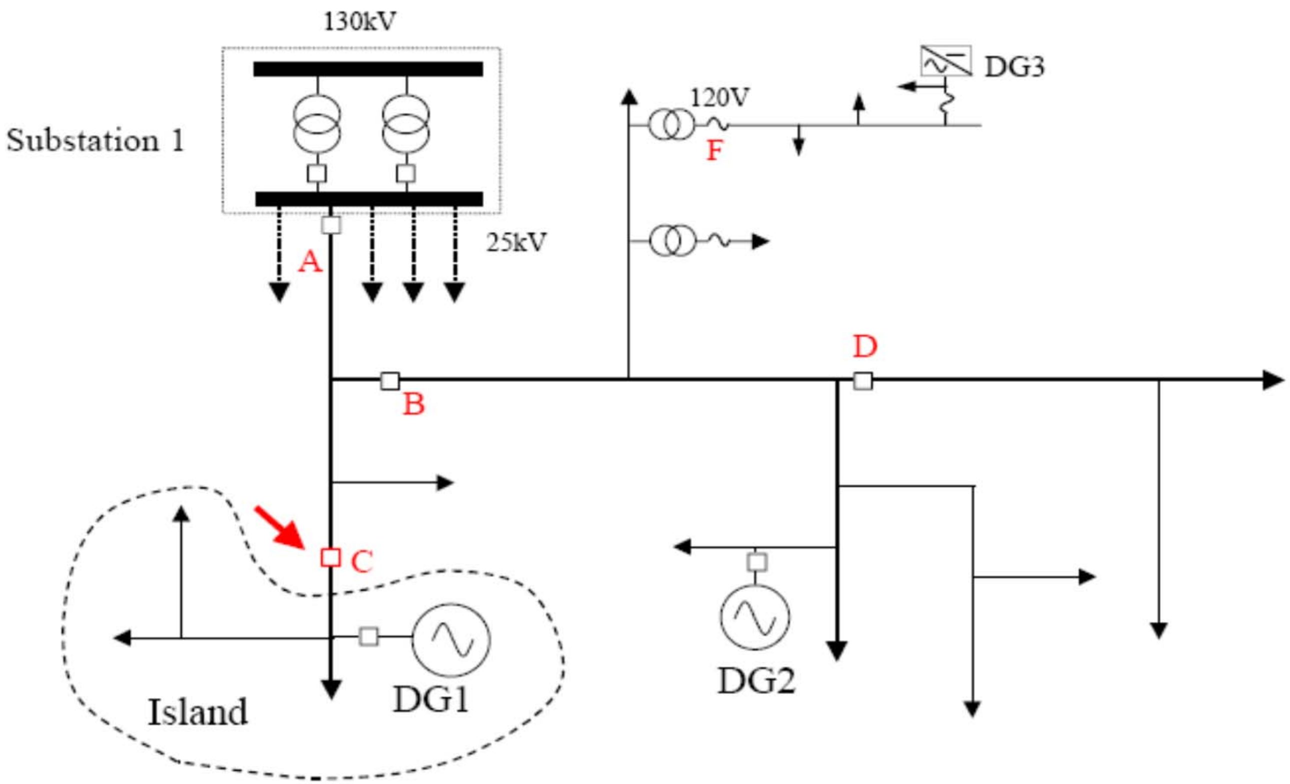
- If the total feeder load is approximately equal to DG output, then DG will try to supply feeder load if utility feeder breaker trips.
- DG and Feeder are now islanded (loss of mains problem).
- Can't close utility breaker without synch check (25).

Anti-islanding Problem



- If islanding did occur, to close the feeder breaker would require monitoring the phase angle across the breaker.
- The autosynchronizer (25A) would need to control voltage and frequency of the DG or the entire utility system. Not practical.
- Islanding is usually avoided.

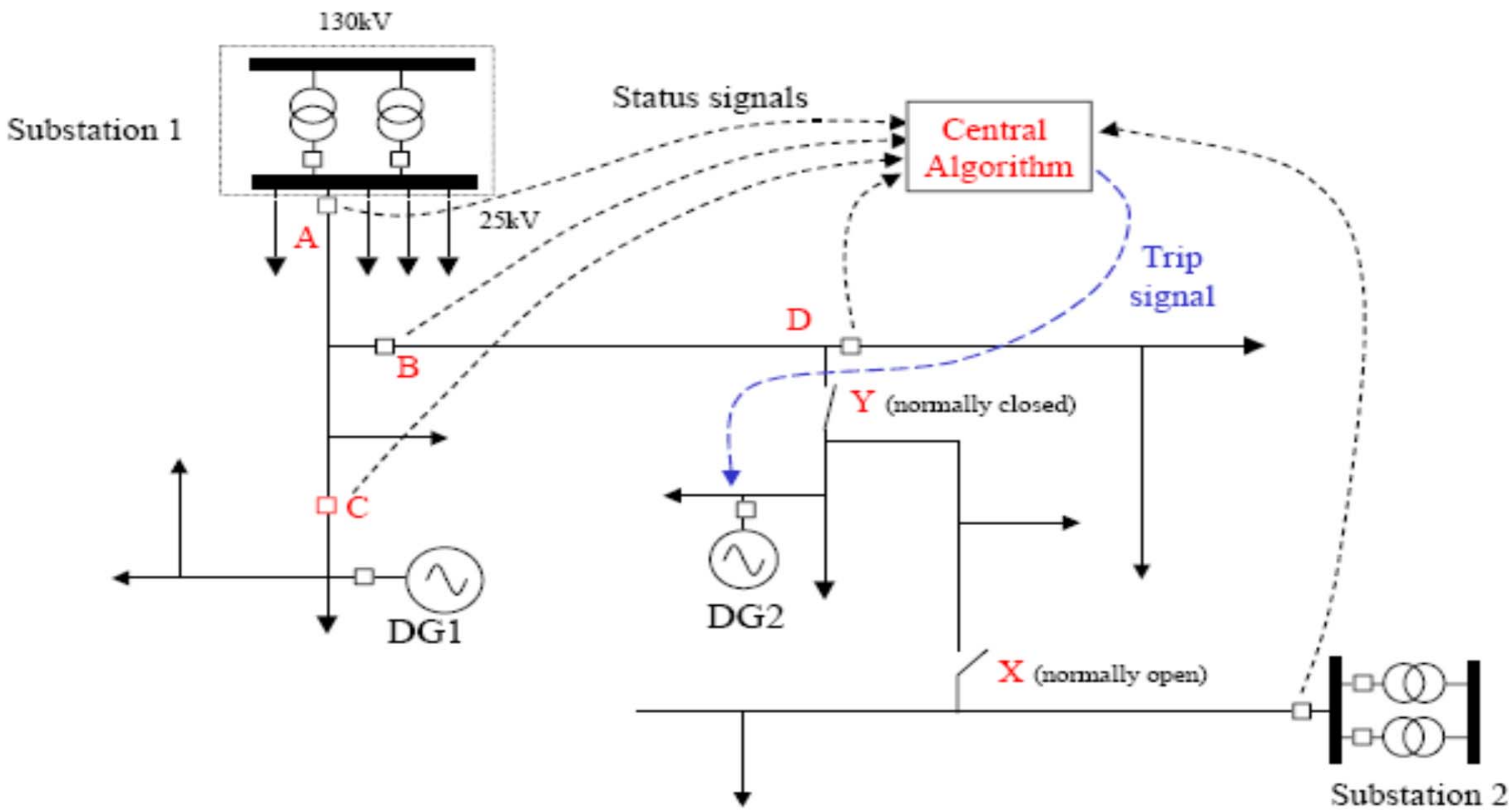
Anti-islanding Problem



Typical distributed system with DG's

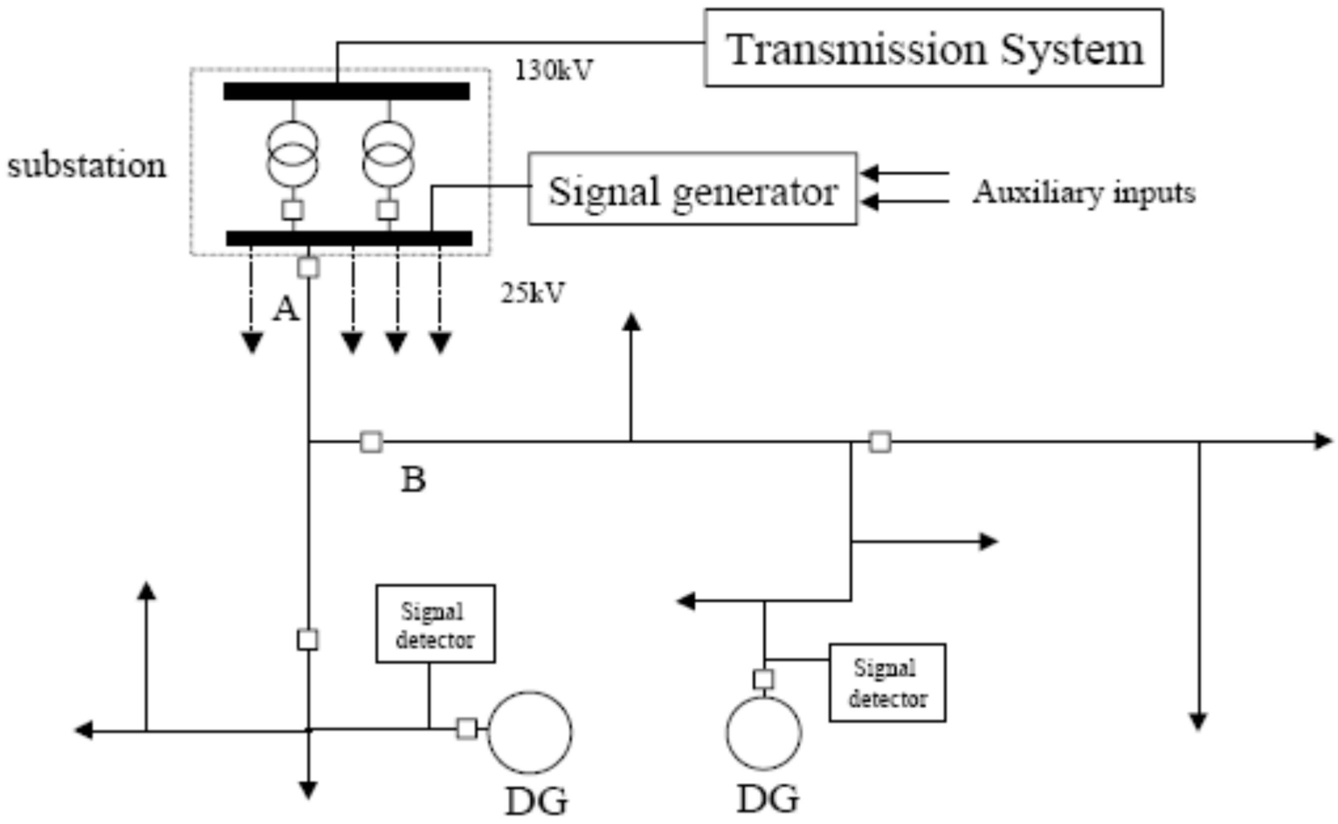
1. Active Islanding Detection Methods

a) Communication based scheme: transfer trip scheme



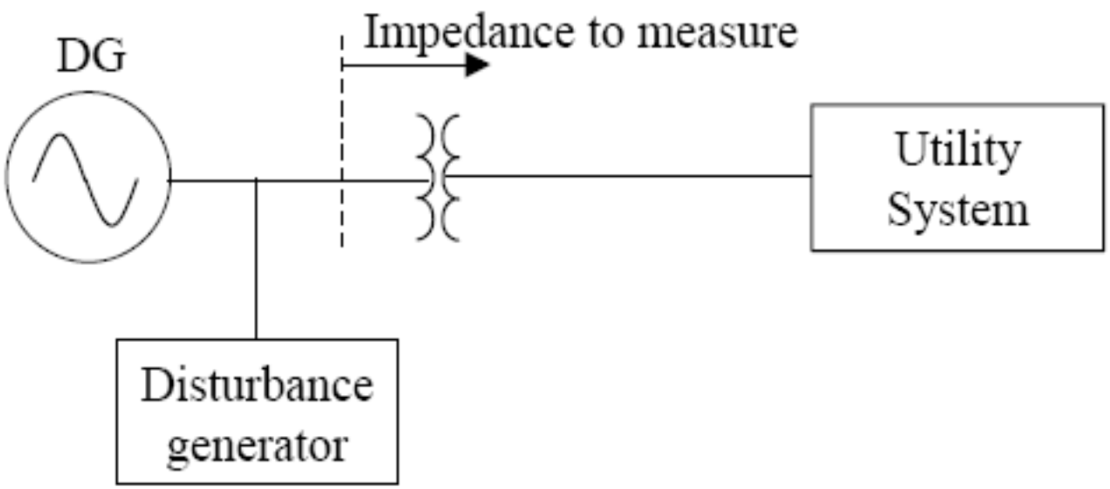
1. Active Islanding Detection Methods

Power Line signaling scheme



1. Active Islanding Detection Methods

b) Method of impedance measurement



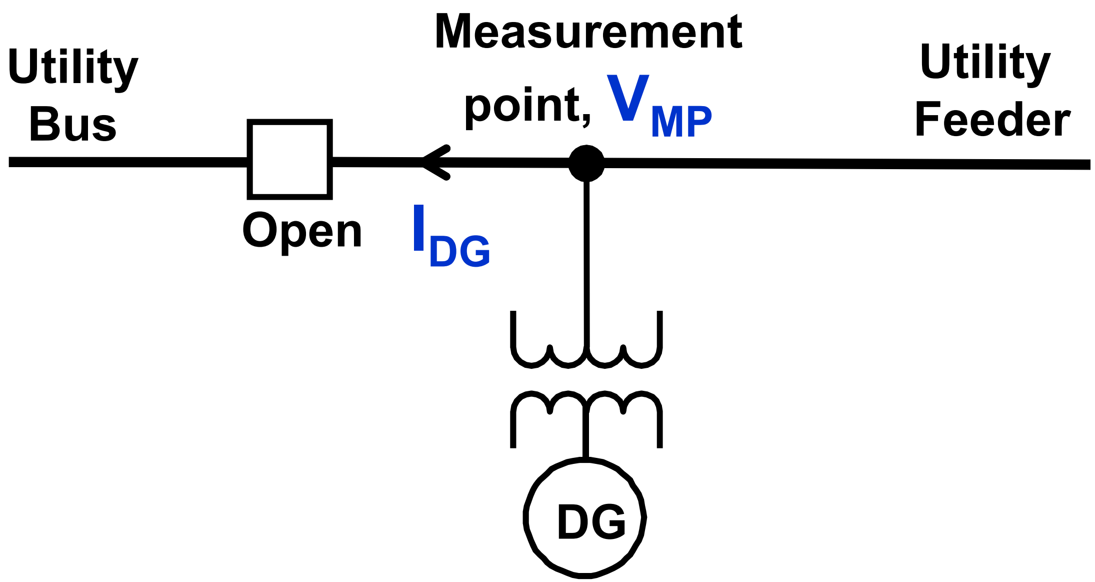
1. Active Islanding Detection Impact

- Degradation of power quality and system stability as DG penetration becomes higher.
- Currently the local islanding detection methods virtually guarantee that the DG will be unable to provide grid support or improve grid stability when the grid is stressed anti-islanding protection disconnects the DG when it detects voltage and frequency excursions on the grid.
- Because of the reclosing practice, anti-islanding techniques must trip DG's within about 200 milliseconds before the breaker is reclosed. Failure to do so will lead to out-of-phase re-energization of the DG.

2. Non-active (Passive) Islanding Detection Methods

a) Over/Under Voltage Amplitude (O/U VA)

Islanding is detected when the amplitude of V_{MP} is out of pre specified interval of voltage amplitude.



2. Non-active (Passive) Islanding Detection Methods

b) Over/Under Voltage Frequency (O/U VF) and Rate of Change of Frequency (ROCOF).

Islanding is detected when the amplitude of V_{MP} is out of pre-specified interval of voltage amplitude. A df/dt detection method (ROCOF) might decrease the detection time and Non Detective Zone. The ROCOF relay is generally accepted as the standard method for islanding protection of the distributed system. These relays monitor the voltage waveform, and operate when the rate-of-change of frequency exceeds a setting and duration exceeds a time delay setting.

2. Non-active (Passive) Islanding Detection Methods

c) Voltage Phase Jump (VPJ).

The phase difference between V_{MP} and I_{DG} is monitored. V_{MP} will jump in phase if $I_{Utility} \neq 0$ at the instant of islanding occurs.

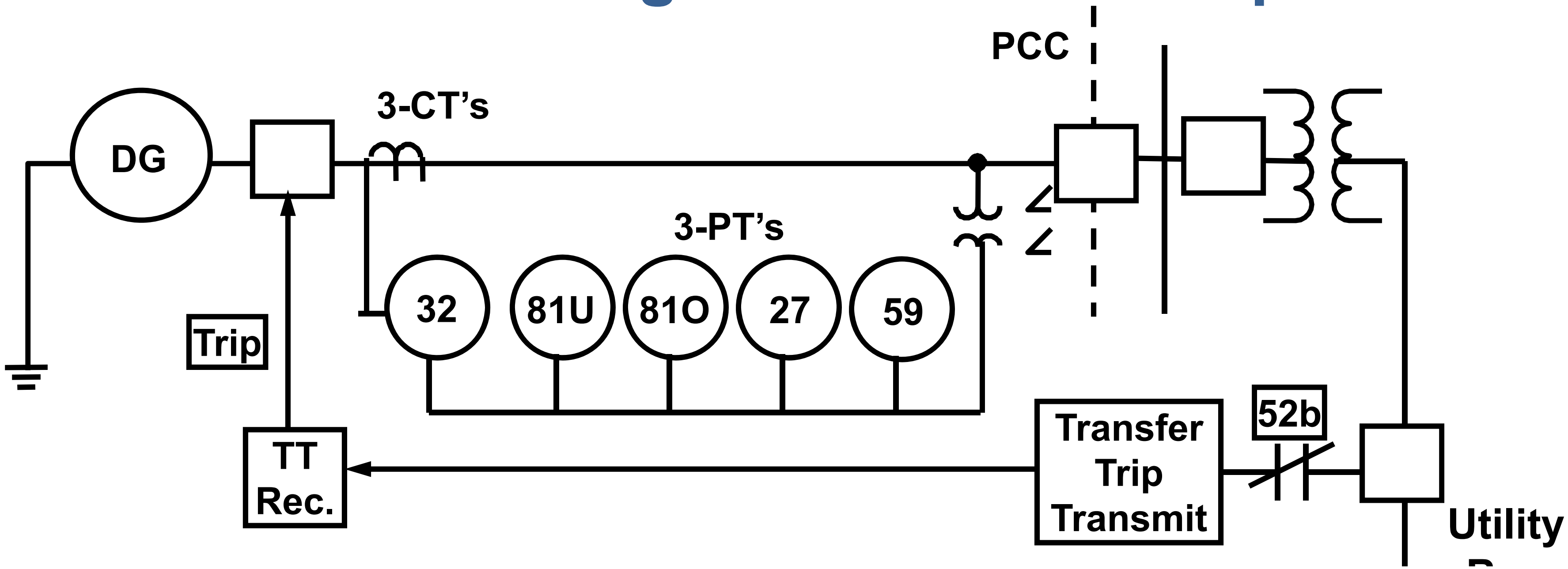
d) Impedance measurement.

Change of positive or negative sequence impedance is applied for islanding detection.

e) Mixture of some sellected methods is applied (multicriteria method).

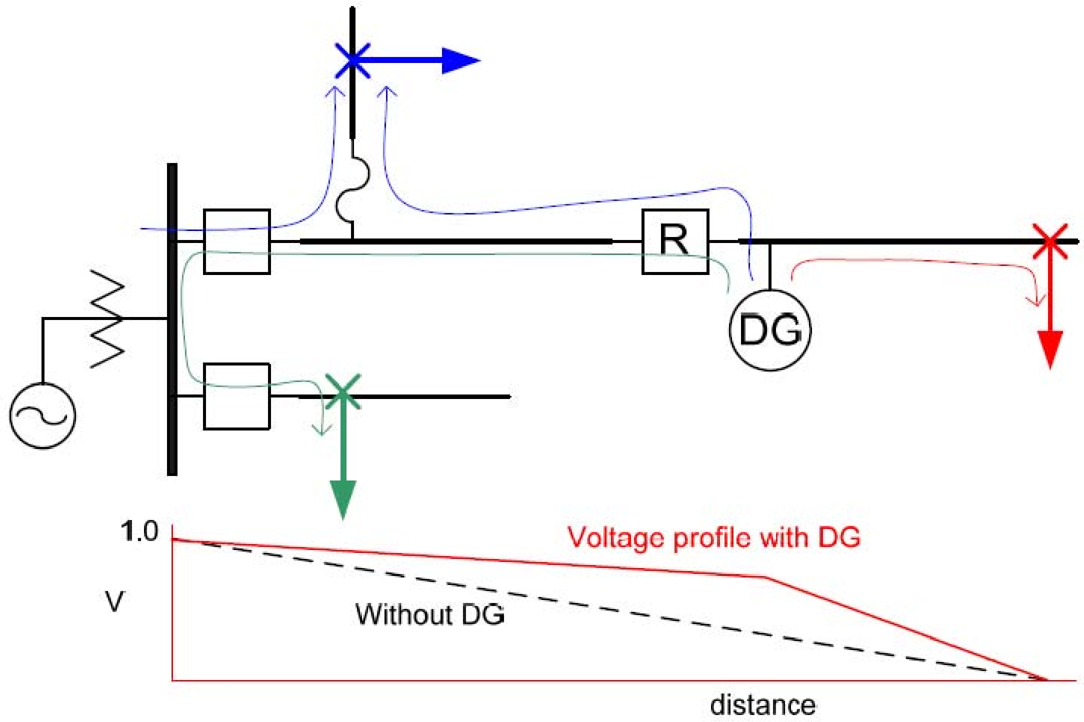
Multicriteria decision making algorithm is needed for selection the final signal.

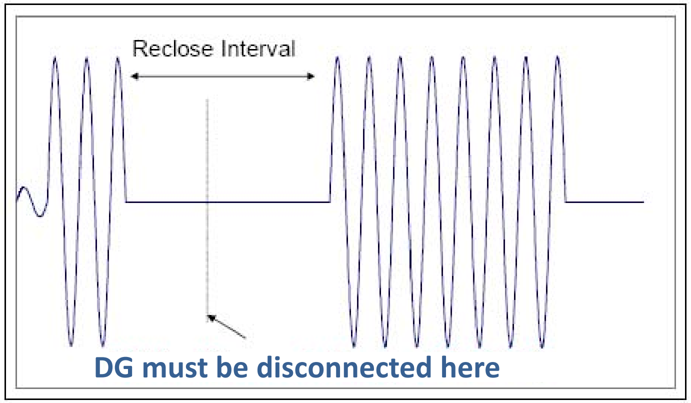
Anti-islanding Protection - example



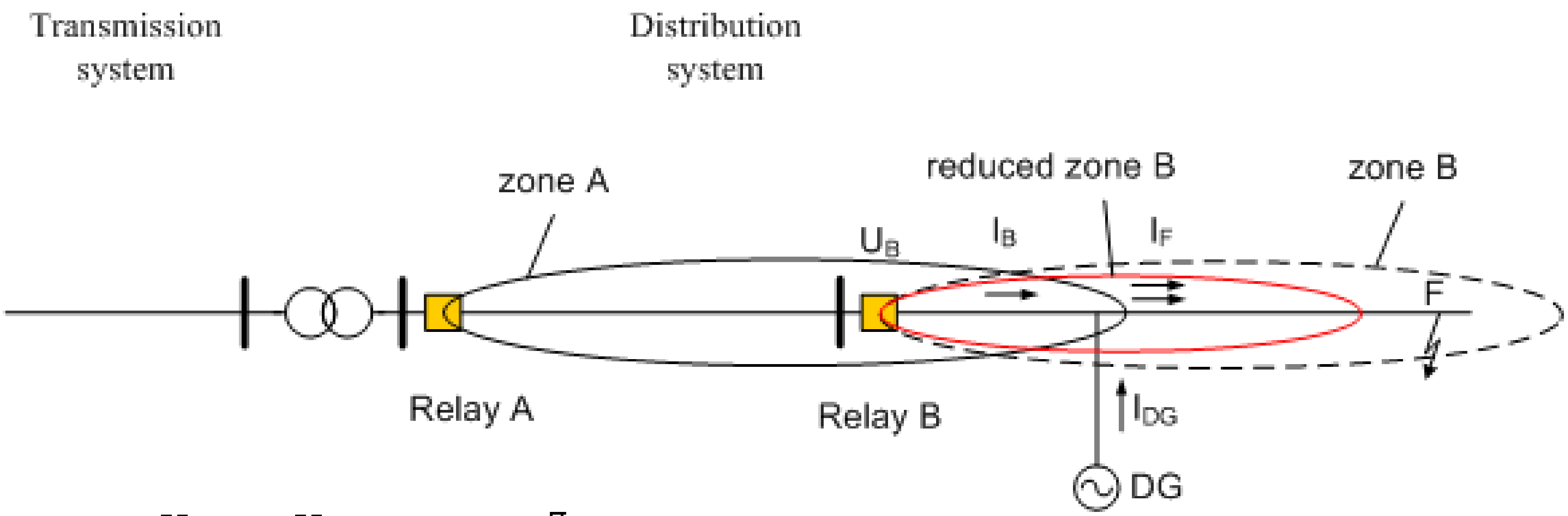
- OF and UF used with load shedding for anti-islanding.
- OV and UV trip for faults on distribution feeder.
- 32 trips for export of power (may be specific level).
- DG must consider utility reclosing to ensure clearing prior to reclose.

DG Impact on Protection and Reclosing





DG Impact on Protection and Reclosing



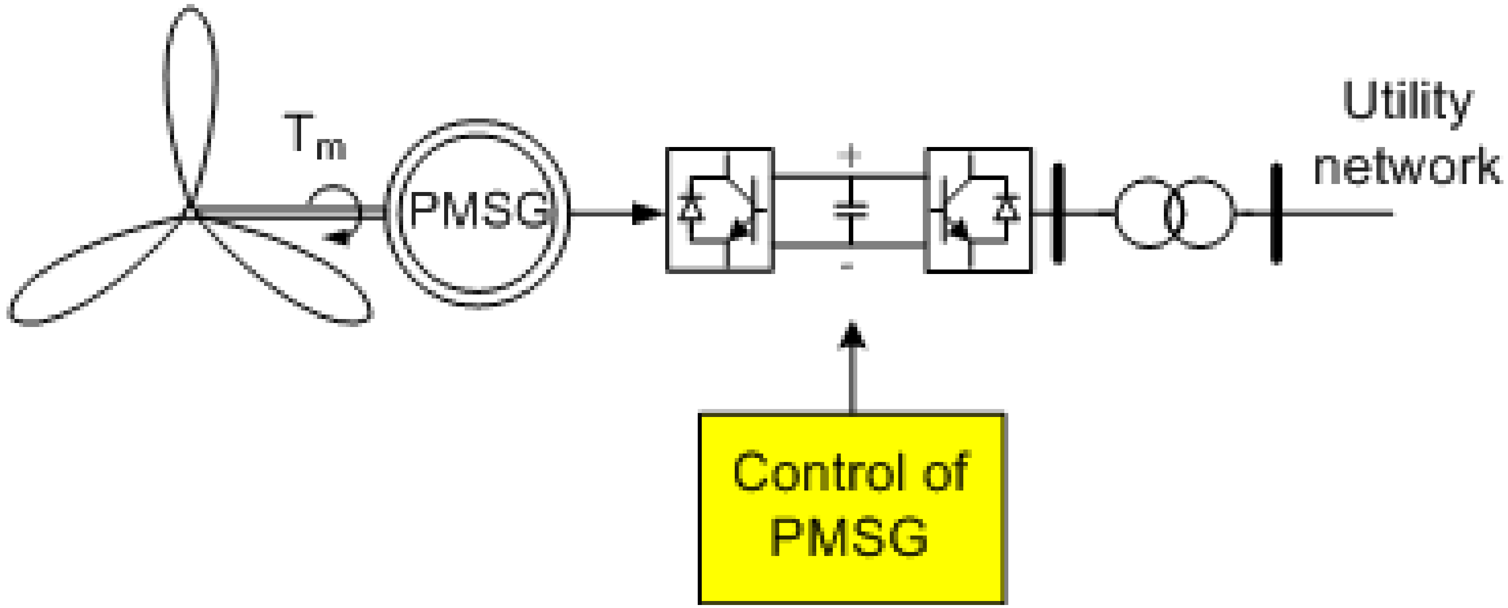
$$Z_B = \frac{U_B}{I_B} = \frac{U_B}{I_F - I_{DG}} \qquad d = \frac{Z_B}{Z_L^{'}} \text{ - zone length}$$

The total fault current is composed of the following contributions from both the source I_B and the distributed generation current I_{DB}. The Relay B measures only current I_B what reduces protected zone (relay under-reach).

Type of Generation

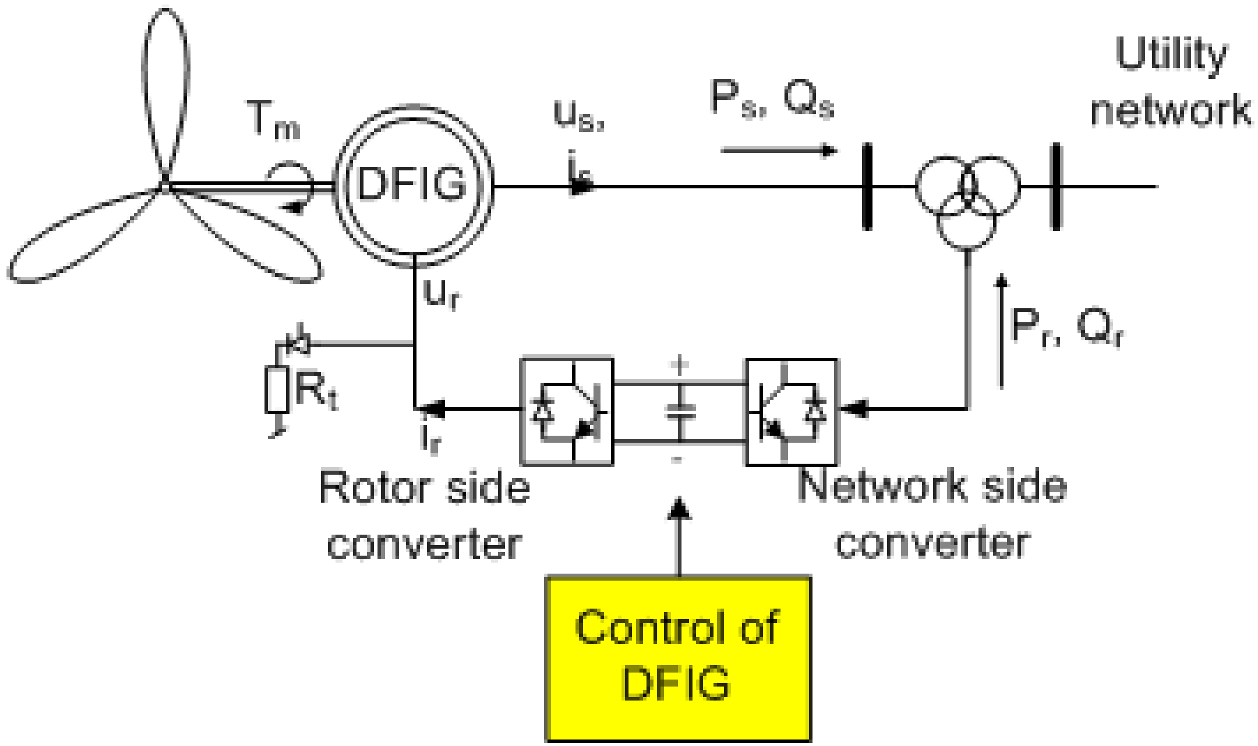
- **Rotating machine - speed controlled to match utility 50/60 Hz**
  - **Synchronous - capable of supplying load as an independent source with voltage and frequency control.**
  - **Induction - cannot operate alone since it gets its excitation from the ac system to which it is connected.**
  - **May be single phase or three phase**

Type of Generation



Permanent Magnet Synchronous Generator

Type of Generation



Dobly Feed Induction Generator

Type of Generation

- **Power inverters change DC to AC electronically. The DC source could be batteries, fuel cells or photovoltaic panels.**

  -Line commutated inverters need an external source of reactive power to operate and would normally shut down when the utility tie opens.

  - Self commutated inverters can continue to supply power independently and do not require a source from the utility. These inverters should be tripped when the utility tie opens.

Type of Generation

Power inverters change DC to AC electronically. The DC source could be batteries, fuel cells or change non-50Hz generation to 50Hz power. The AC source could be micro-turbines generating 400Hz.

-These Static Power Converters can synchronize to the 50Hz utility system faster than a synchronous generator where the excitation must be controlled to match voltage and frequency of the utility.

- These static power converters are also known as isochronous generators.

Converters connected Generation