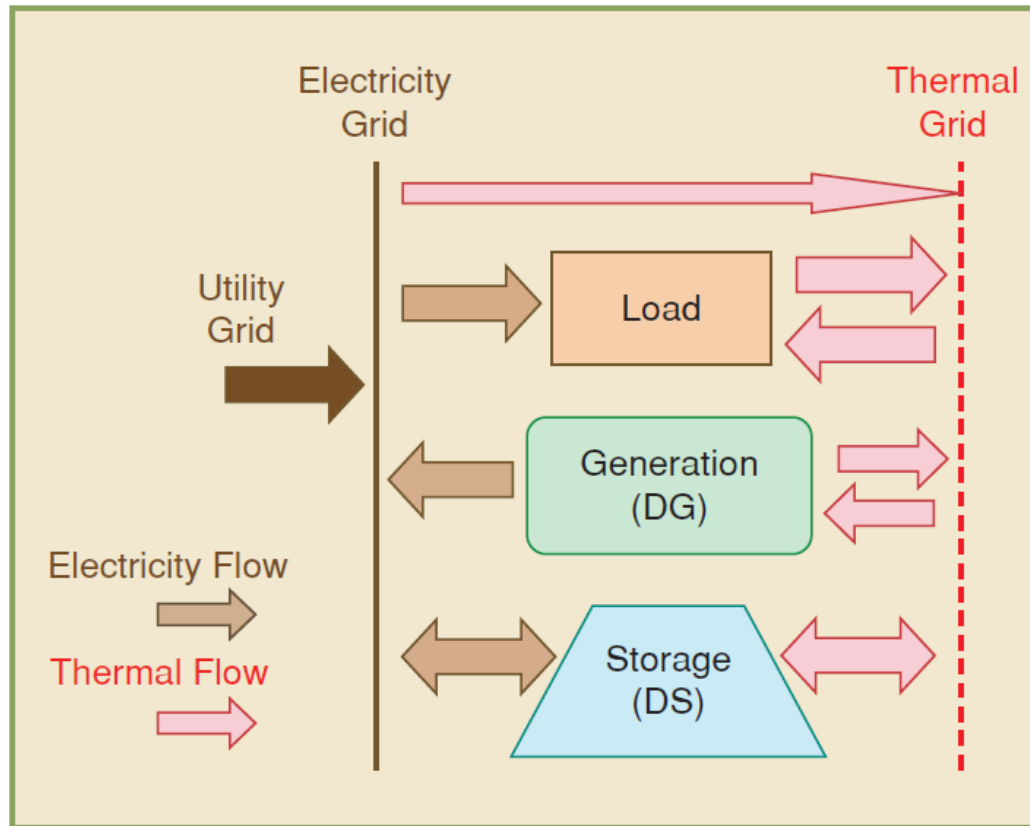


ELG4126: Microgrids



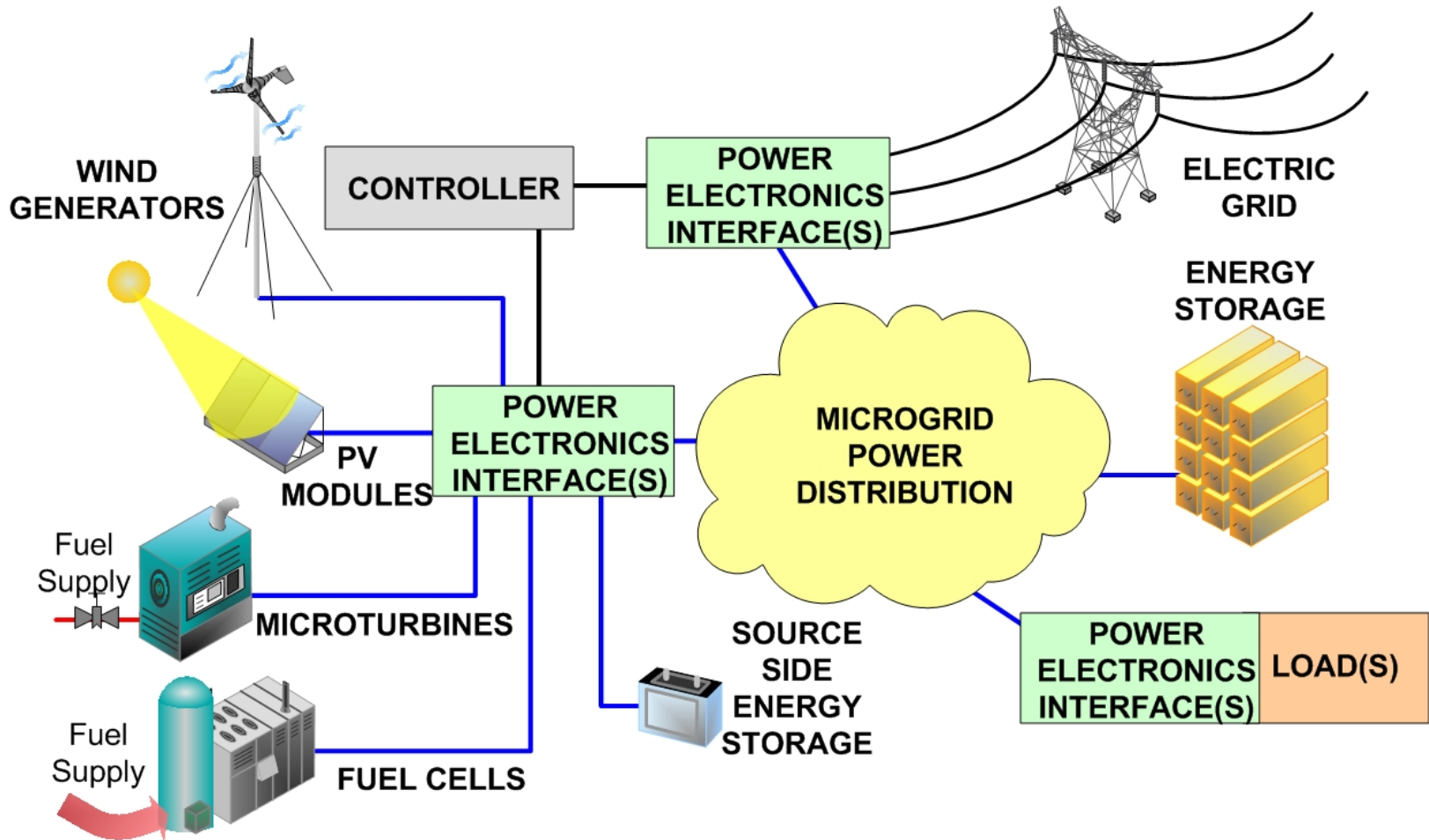
Small Electrical Systems (Microgrids)

- A microgrid is a localized, scalable, and sustainable power grid consisting of an aggregation of electrical and thermal loads and corresponding energy generation sources.
- Microgrids are electrical sub-networks within the distribution grid that can be disconnected from the larger system; in this 'islanded' mode, microgrids are self-sufficient and can autonomously supply their internal load from connected distributed generation (DG) within. However, currently the practice of intentional islanding or autonomous operation of DG permitting such operation is not encouraged or permitted by utilities.
- Designed, built, and controlled by "customers" based on internal requirements subject to the technical, economic, and regulatory opportunities and constraints faced.

Microgrid Components

- Microgrid components include; distributed energy resources (including both energy storage and generation), control and management subsystems, secure network and communications infrastructure, and assured information management.
- When renewable energy resources are included, they usually are of the form of small wind or solar plants, waste-to-energy, and combined heat and power systems.
- A cluster of small (< 500 kW) sources, storage systems, and loads which presents itself to the grid as a legitimate entity, i.e. as a good citizen.
- Interconnected with the familiar wider power system, or macrogrid, but can island from it.

Microgrid Components

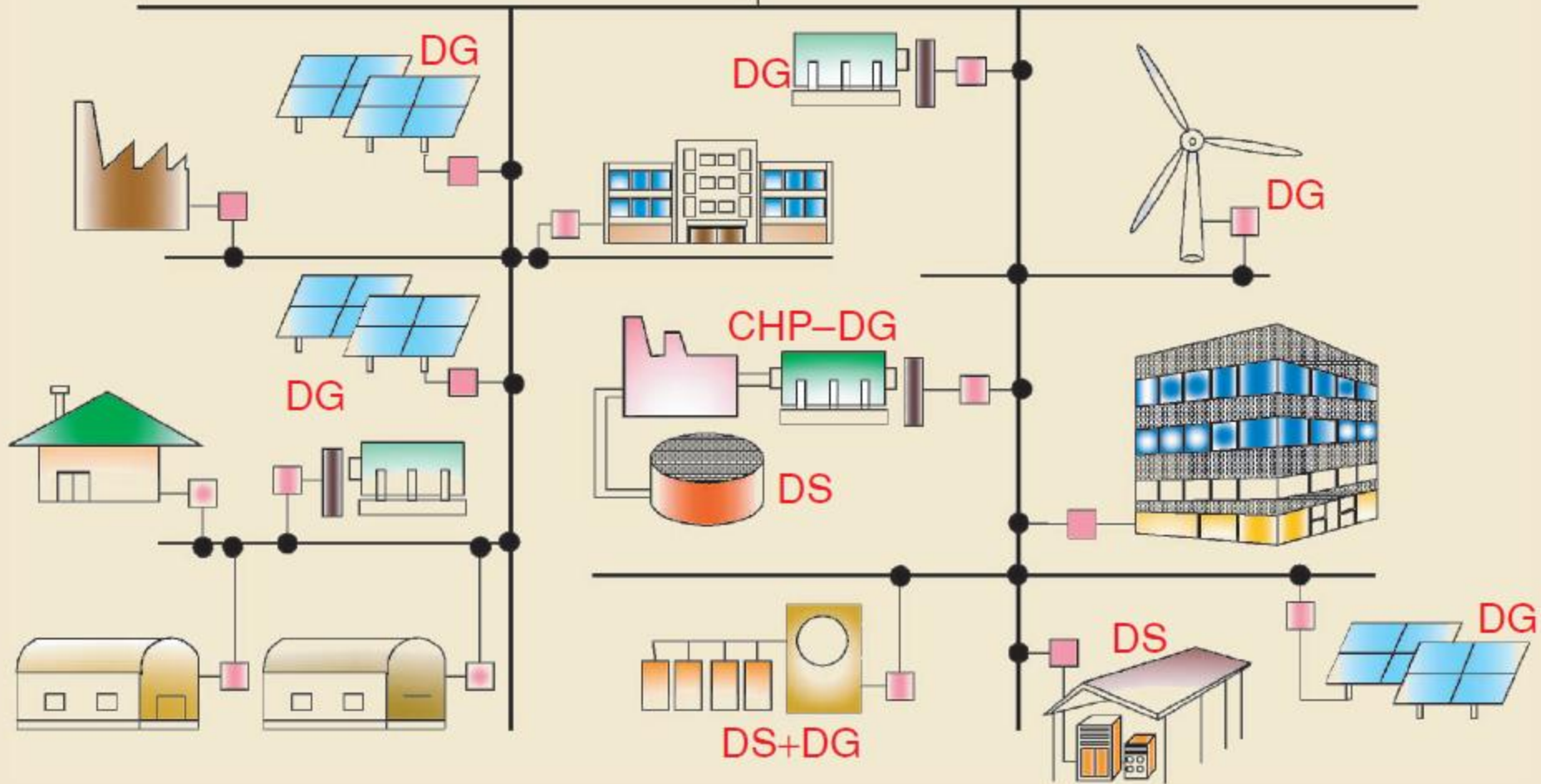


Utility Grid

Substation

PCC

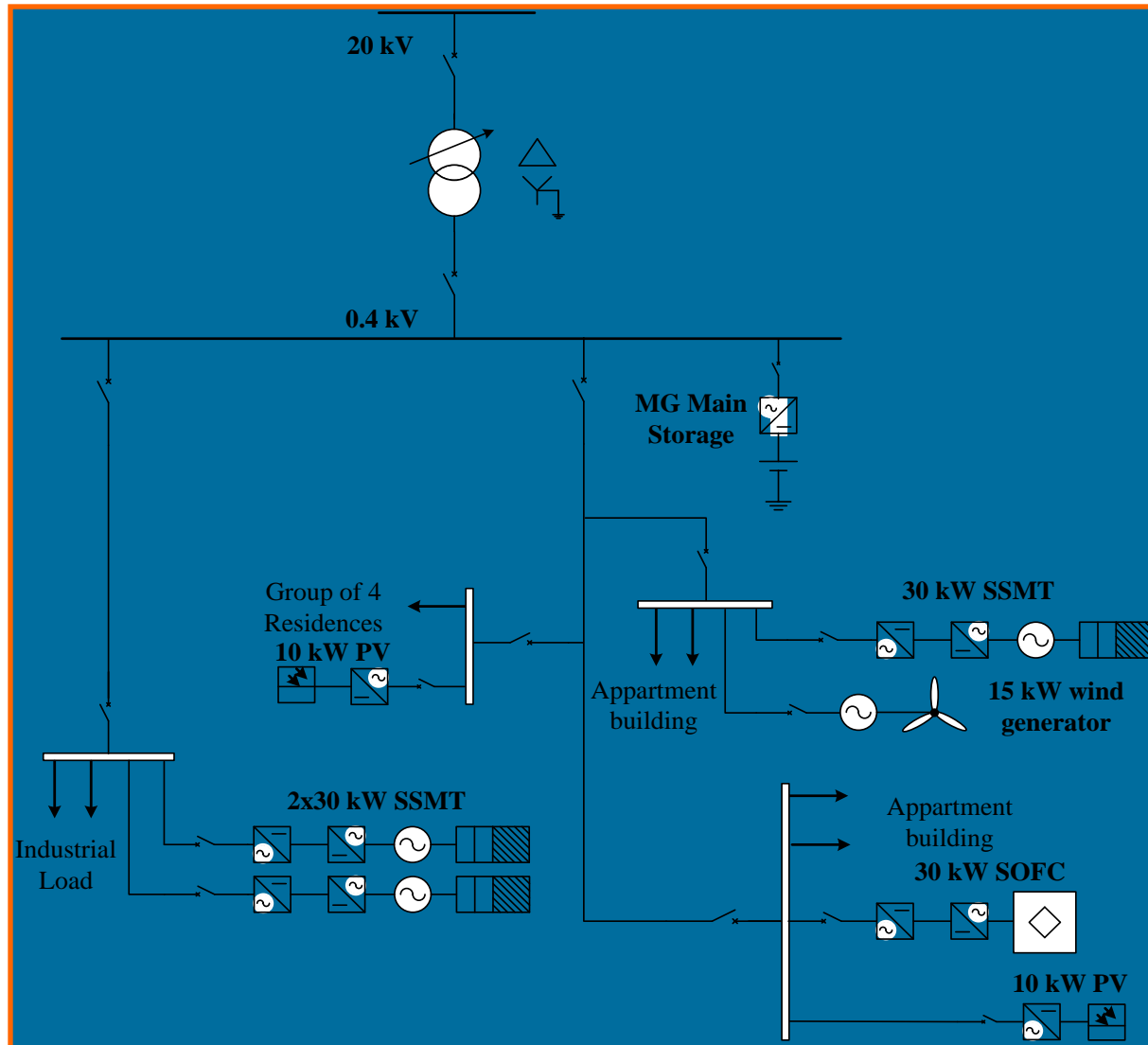
Microgrid



Canadian Interests

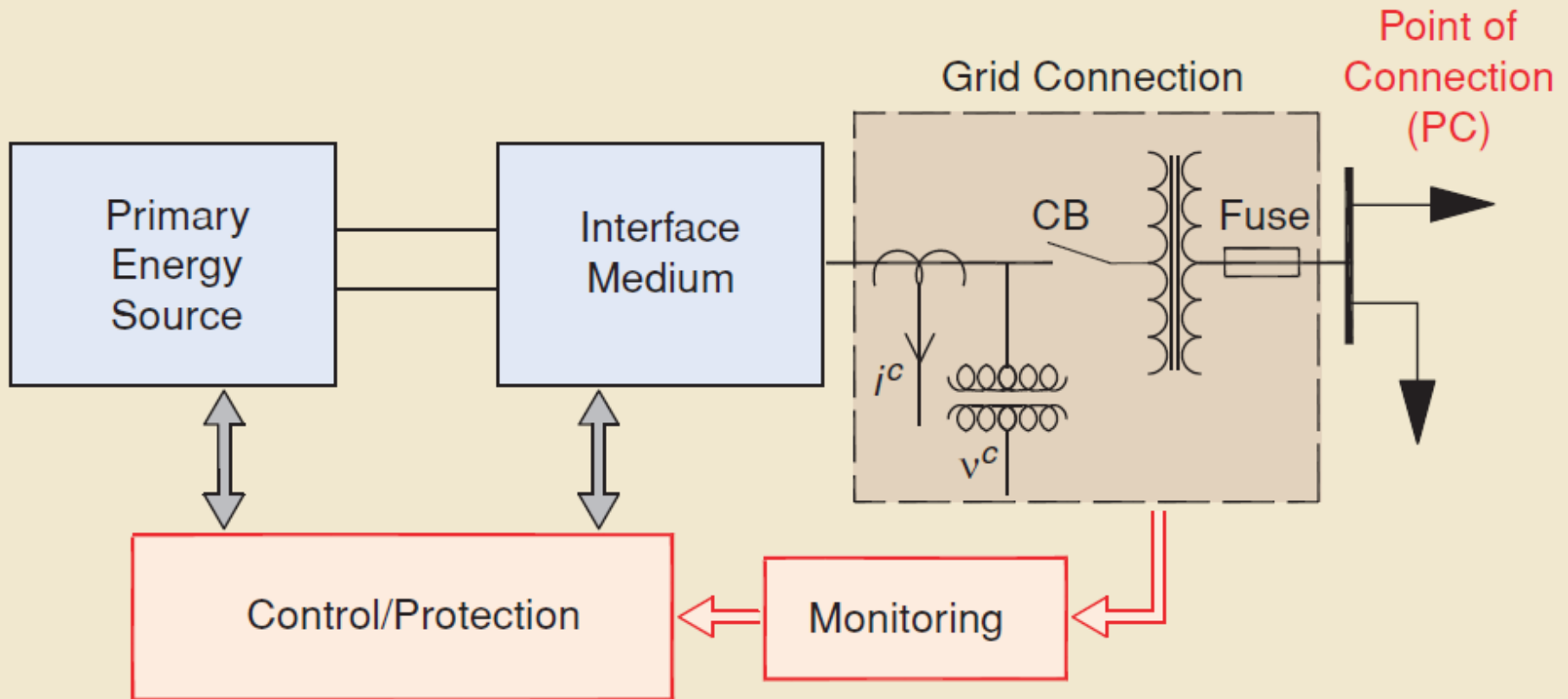
- Electrification of remote communities and islands:
 - Power generation systems for Non-Integrated Areas, and Northern communities.
 - Reduce the use of diesel fuel in remote communities.
- Securing power supply to the customers:
 - Continuity of supply (improved service on rural feeders)
 - Intentional islanding subsequent to faults on upstream feeders.
 - Pre-planned islanding during substation maintenance
- Managing load growth and peak shaving.
- New approach for distribution system planning (new systems and upgrades).

MicroGrids Dynamic Simulation: Test System



Interface of the DR with the Grid

This is important for Case Study 2



Standards

- There are several standards specifying various aspects grid interconnection of a local power generation source. Arguably the most important one is IEEE 1547.
- IEEE 1547 has several parts:
 - Main body
 - IEEE Standard 1547.1 “IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems.”
 - IEEE Standard 1547.2 “IEEE Application Guide for IEEE Std 1547™, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems.”
 - IEEE Standard 1547.3 “IEEE Guide for Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems.”
 - IEEE Standard 1547.4 “IEEE Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems.”
 - IEEE Standard 1547.5 has not been issued, yet. Its intended scope is to address issues when interconnecting electric power sources of more than 10 MVA to the power grid.
 - IEEE Standard 1547.6 “IEEE Recommended Practice for Interconnecting Distributed Resources with Electric Power Systems Distribution Secondary Networks.”
 - IEEE Standard 1547.8 has not been issued, yet. Its intended scope is to provide supplemental support for implementation methods for expanded use of the previous standards, for example when addressing issues with high penetration of residential PV systems.

Main Provisions from IEEE 1547

- The microgrid must “not actively regulate the voltage at the PCC.”
 - The grounding approach chosen for the local area power and energy system (LAPES) must not create overvoltages that exceed the ratings of the equipment connected to the main grid or must not affect ground fault protection coordination in the main grid.
 - The distributed resources in the LAPES must be able to parallel with the main grid “without causing voltage fluctuations at the PCC greater than $\pm 5\%$ of the prevailing voltage level of the Area electric power system (EPS) at the PCC” and flicker must be within acceptable ranges.
 - The LAPES must not energized the main grid when the main grid is not energized.
 - Each distributed resource (DR) “unit of 250 kVA or more or DR aggregate of 250 kVA or more at a single PCC shall have provisions for monitoring its connection status, real power output, reactive power output, and voltage at the point of DR connection.”
 - A visible-break isolation device must be located between the main grid and a DR unit only when required by the main grid provider practices.
 - The interconnection system must meet applicable surge and EMI standards.

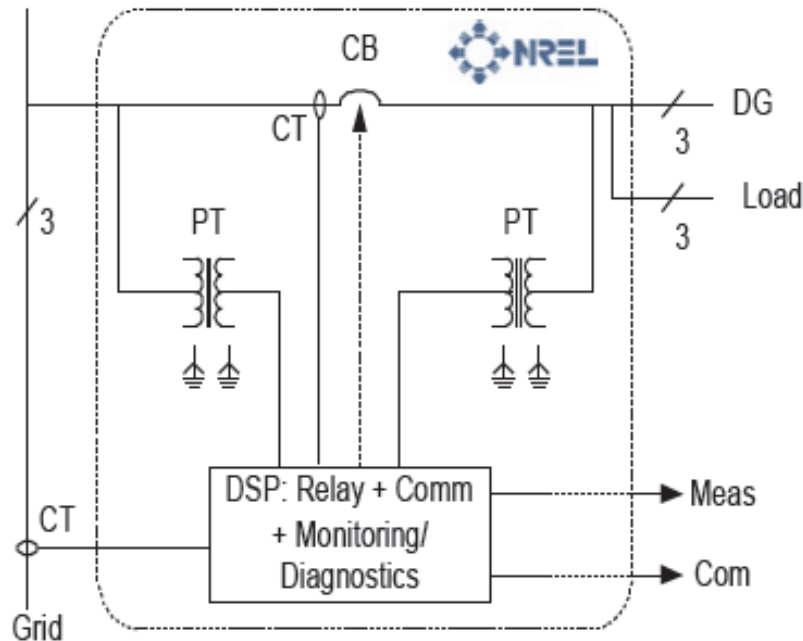
- When a fault occurs in the main grid circuit to which a LAPES is connected, then the micro-grid local power generation units must stop to power this circuit before reclosure from the main grid happens.
- The interconnection system must be able to measure relevant indicated voltages and frequencies at the PCC or the point of connection of DR and disconnect within a given allowed time all local power generating units in the micro-grid when these measured voltages or frequencies fall within a range specified in a table in this standard. For example, when voltages fall below 50 % of the base voltage, the LAPES must disconnect its DR within 0.16 seconds (one 60 Hz cycle). The time extends to 2 seconds for voltages between 50 and 88 % of the base voltage. Disconnection must occur within 1 second if measured voltages are between 110 and 120 % of the base voltage and within 0.16 seconds if the voltage exceeds 120 % of the base voltage. For frequency measurements, any DR of 30 kW or less must disconnect 0.16 seconds if the measured frequency is above 60.5 Hz or below 59.3 Hz. The same disconnect time applies for DR of more than 30 kW when the frequency exceeds 60.5 Hz, but for the lower range at these power levels disconnect within 0.16 seconds must occur if the frequency falls below 57 Hz, whereas disconnection is adjustable between 0.16 and 300 Hz if the frequency falls between 59.8 and 57 Hz.
- Reconnection of a LAPES to a main grid may occur at least 5 minutes after voltages and frequency fall within indicated required ranges.

Interconnection Techniques

- Interconnection methods:
 - Directly through switchgear
 - Power electronic interfaces
 - Static switches
- Directly through circuit breakers:
 - Relatively simple and inexpensive
 - Slow (3 to 6 cycles to achieve a complete disconnection).
 - Since electrical characteristics on both sides of the circuit breakers must be the same, then, electrical characteristics on the micro-grid side are dependent on the grid characteristics. For example, use of a circuit breaker implicitly limits the micro-grid to have, at least partially, an ac power distribution system in order to match the grid's electrical characteristics.
 - Power flow through the PCC cannot be controlled.

Interconnection Techniques

Directly through circuit breakers: Example of one of such systems:



Use of static switches: Usually based on SCRs in antiparallel configuration to allow bidirectional power flow

Interconnection Techniques

- Power electronic interfaces:
 - It is the costlier option but it is also the most flexible one.
 - Allow for power distribution architecture characteristics on both sides of the PCC to be completely different.
 - Both real and reactive power flow can be controlled.
 - Reaction times to connection or disconnection commands are similar to those provided by static switches, although in the case of a power electronic circuit, its response also depends on its dynamic performance, given by its controller, topology, and internal energy storage components characteristics.
 - Still, in many cases, a circuit breaker will still be required at the grid-side terminal of the power electronic interface with a LAPES in order to provide a way to physically disconnect the micro-grid from the grid.
 - Also, similarly to static switches, the presence of a power electronic circuit will lead to some power losses not found in the approach using mechanical interfaces.

Islanding

During the transition into island operation it is important that:

- Voltage disturbances are quickly dampened and that protection schemes both inside the LAPES and in the grid are not affected.

When the transition is completed it is important that:

- The microgrid has sufficient local power generation and energy storage in order to ensure that loads are powered with the agreed quality level. For example, in ac micro-grids it is important that distributed resources are able to provide real and reactive power to the specified load range. This is particularly important in order to avoid loss of stability if there are large motors in the LAPES that require significant amounts of reactive power during startup
- Also for ac microgrids, their control systems must be able to regulate both voltage and frequency within acceptable ranges. In dc micro-grids, neither frequency regulation nor reactive power generation are issues to consider.

Islanding

- Eventually, it can be anticipated that the micro-grid would be connected to the main grid again. Grid connection of dc micro-grids or ac micro-grids with a power electronics interface with the main grid tends to be simpler than the case of ac micro-grids connected to the main grid through circuit breakers, contactors, or static switches because in the dc micro-grid and the ac micro-grid with a power electronics interface cases reconnection control resides only in this power electronic interface. That is, the controller in this power electronic interface would be controlled in order to realize on its grid side some voltage waveform so its amplitude, frequency and phase angle are within specified limits to allow reconnection.
- In the other ac micro-grid cases—those directly connected to the main grid through mechanical switchgear or static switches—reconnection is more complicated because there is no possibility of directly controlling the voltage waveforms at the PCC. In this case, ensuring that the voltage, frequency and phase angle are within acceptable limits depend on how the LAPES distributed resources are controlled.

Islanding

According to IEEE Standard 1547.4 these approaches can be distinguished in this case of ac micro-grids in order to achieve a successful reconnection:

- **Active synchronization:** In this approach, the LAPES controller matches the voltage signal on the PCC micro-grid side to those of the PCC on the grid side immediately before closing the islanding devices, such as a circuit breaker. Implementation of this approach requires measuring these three voltage signal parameters—amplitude, frequency and phase angle—on both sides of the PCC. A communications channel in order to exchange information between the micro-grid and the main grid is also necessary. This need for sensing and communications may lead to a higher failure rate as the sensing and communications subsystems may become a single point of failure.
- **Passive synchronization:** In this approach a device is used to monitor the voltage at both sides of the PCC and allows the LAPES to connect to the main grid only when the voltage signal on the LAPES side is within some given required range of the main grid analogous voltage parameters. Like the active synchronization approach, passive synchronization requires sensing and communications, leading to the same potential reliability concerns. In addition, this method may be slower than active synchronization.
- **Open transition:** This approach is more basic than the other two, because the method involves connecting both ends of the PCC after interrupting disconnecting the LAPES load. Once the micro-grid is connected to the grid then this load is brought back online.

Islanding

- According to IEEE Standard 1547.4, **un-intentional** islanding operations are “inadvertent events that are typically initiated by loss of area EPS or equipment failure, and the DR island system may be automatically sectionalized from the area EPS by protective equipment.”
- Once the island has been established, the same considerations that were considered for the intentional island condition applies to the un-intentional island.
- Contrary to the case of intentional islanding, during an un-intentional island it is not possible to prepare the LAPES for such transition, such as verifying that there is sufficient local generation to sustain a stable operation powering all loads. Hence, in case it is expected that local generation capacity may be insufficient to sustain the load during un-intentional islands, black start functions or standby generators with transfer switches have to be allocated within the LAPES.
- Once the issue in the main grid that led to loss of service to the micro-grid feeder is solved, it may be of interest to reconnect soon the main grid to the micro-grid. However, such connection cannot occur until the voltage and frequency of the grid are stable and within acceptable ranges. In order to ensure meeting such requirement, a delay of up to five minutes may be provided between the time power is restored at the PCC from the main grid and the time reconnection to the LAPES is established.