Market liberalization, environmental issues and incentives for renewable energy sources have resulted in the increase of distributed generation (DG) in the distribution network.

In the past, DGs are treated with a “fit and forget” approach. It is often regarded as a negative load and does not participate in voltage and frequency support of the network.

It was recognized that, with the increase in DG penetration, they should also contribute in the active management of the network.

The concept should also be extended to controllable loads and energy storage devices.

The idea of active distribution network is developed to create an energy efficient, high power quality, reliable and economic network.
Active Distribution Networks – Definition

- CIGRE WG C6.11 “Development and Operation of Active Distribution Networks”, gave the following definition in 2011:

“Active distribution networks (ADNs) have systems in place to control a combination of distributed energy resources (DERs), defined as generators, loads and storage. Distribution system operators (DSOs) have the possibility of managing the electricity flows using a flexible network topology. DERs take some degree of responsibility for system support, which will depend on a suitable regulatory environment and connection agreement.”
### Active Distribution Networks – Features

<table>
<thead>
<tr>
<th>Passive Distribution Network</th>
<th>Active Distribution Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power flow unidirectional, according to load variations, cannot be regulated</td>
<td>Power flow bi-directional, can be regulated</td>
</tr>
<tr>
<td>Stringent requirement for DG connection, “fit and forget”</td>
<td>DGs actively participate in voltage and frequency regulation, “plug and play”</td>
</tr>
<tr>
<td>Loads cannot be controlled</td>
<td>Controllable loads, regarded as part of a distribution resources (DR)</td>
</tr>
<tr>
<td>Traditional technology and compensation equipment, mostly in the form of capacitors.</td>
<td>Utilize ICT (Information and Communication technology), power electronic devices, advanced compensation equipment such as SVC</td>
</tr>
<tr>
<td>Total reliance on the main grid</td>
<td>Have reliable generation capacity to minimize dependence on the main grid. Can potentially operate as an islanded system.</td>
</tr>
<tr>
<td>Operation and planning based on snapshot information.</td>
<td>Utilize load and generation prediction in network planning and operation</td>
</tr>
</tbody>
</table>
Active Distribution Networks - Advantages

- Increased capacity for more distributed generation
- Reduce network losses
- Self-healing
- Improve availability and power quality
- Self-reliance, reduce dependence on the main grid
- Another form of the smart grid concept
Active Distribution Networks - Technology

- Information and Communications Technology
- Renewable generation
- Energy Storage
- Electric Vehicles
- Power Electronics – intelligent source and loads
- Micro grids, virtual power plants
- Big Data technology
- Load and renewable generation prediction
- PMUs (micro PMUs)
- Plug-and-play – Energy router
- Transmission system technology applied to distribution level
• No generally accepted definition exists
• Most in agreement as to characteristics of an active network.....
• *DG, renewables, monitoring, communications and control, preventive and corrective actions, flexible, adaptable, autonomous, Intelligent*
• Aspects of ANM in many international programmes (SmartGrids, Intelligrid...etc)
Specific issues associated with protection

- Reduction of fault detection sensitivity and speed in tapped connections (blinding of protection)
- Reduced reach of impedance relays
- Unnecessary tripping for faults in adjacent lines due to fault contribution of the DG (sympathetic tripping)
- Changes in the value and direction of short circuit currents, affecting the co-ordination and operation time of the overcurrent relays
- Impact of the reduced fault contribution of converter based generators on protection performance
- Unintended islanding which can prevent automatic reclosure and operation without effective grounding
- Out-of-step conditions
- Over-voltages due to resonance conditions
- Increased fault levels exceeding the capacity of the existing switchgear
Conventional distribution networks

• Operated radially
  • Designed for unidirectional power flow
  • Protected with over-current protection relays, reclosers and fuses
• Fault current magnitudes and directions becomes unpredictable, potentially causing problems:

- false tripping of feeders (sympathetic tripping);
- lack of coordination between protection devices;
- other problems.
Islanding operation

- Reduced fault levels
- Changed fault current direction
- System control to maintain voltage and frequency

11 kV
Tapped connection of DG - Fault current contribution for a fault downstream the DG

Utility equivalent

DG equivalent on a tapped connection
Fault Levels

- Fault level provides fault current when a short circuit occurs which causes operation of protective relays
- Too high fault currents can be hard to interrupt
- Too low and the protective devices may not operate
- The problem with high penetration of DGs is the large variation of fault levels.
Converter Interfaces (1)

System with conventional generation

- System fault levels are only restricted by the capacity of generators and the equipment in the path of the fault.
- Network protection coordination is relatively straightforward - local protection operates first, then backup...
- Ultimately generator protection may trip if there is a massive failure of network protection.
Converters normally act to limit fault current

Converters’ inbuilt protection may stop conduction very quickly before “correct” downstream protection operates

May lead to protection coordination problems
Prevention of unintentional islanding – Loss of mains (LOM) protection

- Frequency
- Voltage
- Residual Voltage
- ROCOF
- Voltage Vector Shift

- O/C & E/F
- NPS Voltage
- NPS O/C
- Check Synch

Islanded load fed unearthed

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Loss of mains (LOM) performance requirements - sensitivity

- Standards are available for DG connection requirements (IEEE1547, G.59(UK), GB/T 19939-2005)
- Loss of mains (LOM) should be sensitive under all possible load and generation scenarios.
- The most challenging scenario is when the local load closely follows the generator output both in terms of active and reactive power.

![Diagram of interconnected system with notations for P_{load}, Q_{load}, P_{gen}, Q_{gen}, LOM, interconnected system, feeder, G, load profile, generation profile, and risk of undetected island.]}
Primary System Challenges

- More complex fault current distributions due to DG
- Changes in grading paths due to reconfiguration and further interconnection
- Increased variation in fault levels from min to max
  - Fault current limiters
  - Islanding operation with reduced fault levels
- Increasing sensitivity of demand and certain generators
  - Generator stability
Secondary System Opportunities

- Multi-function IEDs
  - Much of the capability remains unused as protection functions often disabled
  - Provide alternative functions to support ADN
- Greater levels of communication access and quality
- Greater interest in innovation from network operators
A Vision for Protection Research

- Loss of mains Protection
- DG Control
A Vision for Protection Research

- Loss of mains (LOM) Protection
- DG Control

- Protection of DC systems
- Protection of DGs
- Non-conventional Protection
- Active Protection methods
- Adaptive Protection
- Fault Management
- Wide area protection
A Vision for Protection Research

- Loss of mains (LOM) Protection
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- LOM with comms
- Centralised protection

- Adaptive Protection Architecture
- Adaptive Protection Testing Environment

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- Fault location
- Fault level estimation

Protection of DC systems
Non-conventional Protection
Active Protection methods
Fault Management
Adaptive Protection
Wide area protection
Protection of DGs
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- LOM with comms
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- Adaptive Protection Testing Environment
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- Fault location
- Fault level estimation
- Dynamic Line rating Protection using weather information
- Active LOM Methods
- Coordination of protection with power electronics
- Protection of DC systems
- Protection of DGs
- Non-conventional Protection
- Wide area protection
- Adaptive Protection
- Active Protection methods
- Fault Management
A Vision for Protection Research

- Fault detection methods
- Protection co-ordination
- Dynamic Line rating Protection using weather information
- Active LOM Methods (active frequency drift)
- Coordination of protection with power electronics
- Loss of mains Protection
- DG Control
- LOM with comms
- Centralised protection
- Adaptive Protection Architecture
- Adaptive Protection Testing Environment
- Fault Current Limiter applications
- Fault location
- Fault level estimation

Protection of DC systems

Protection of DGs

Non-conventional Protection

Active Protection methods

Fault Management

Adaptive Protection

Wide area protection
Enhanced Role for Protection IEDs

PROTECTION IED

REVISED PROTECTION FUNCTIONS?

ADN & SMARTGRID SUPPORT

REMOTE MEASUREMENT?

LOCAL CONTROL?

LEVEL OF AUTONOMY?
REVISED PROTECTION FUNCTIONS?

- SOURCE INFEED LEVELS
- NETWORK TOPOLOGY
- CLEARANCE TIMES

ADAPTING SETTINGS TO BETTER REFLECT NETWORK CONDITIONS
ADN & SMARTGRID SUPPORT

- QUALITY OF SUPPLY
- FACILITATING DG CONNECTION
- ASSET UTILISATION

SUPERVISORY CONTROL, REGULATION & METERING
"One solution fits all" or flexibility...

- Modern Communications
- Interconnection
- Reconfiguration
- Network Support Technologies
- Switchgear Technology
- DG Connection
- Numerical Relays
- Sensitivity
- Selectivity
- Speed of Response
- Adaptive Protection
Protection Scheme for Campus Microgrid

Protection Device 1: Installed at the PCC, this device is used to monitor islanding conditions so as to action the transition from parallel mode to islanded mode or vice versa.

Protection Device 2: Installed at the distributed generation’s feeder terminal, it operates for either the busbar fault or the feeder fault.

Protection Device 3: Installed at the feeder terminal feeding the loads, its protection in parallel mode is overcurrent.
Reference to IEEE 1547 and China’s national standard GB/T 19939-2005 “Technical requirements for grid connection of PV system”

Fig. 8. (a) Over-/Under- Voltage protection settings of PD1 and PD2.

(b) Over-/Under- Frequency protection settings of PD1 and PD2.

Fig. 9. (a) Overcurrent protection settings of PD2 and PD3.

(b) Zero-sequence overcurrent backup protection settings of PD2 and PD3.
Reference to IEEE 1547 and China’s national standard GB/T 19939-2005 “Technical requirements for grid connection of PV system”

During islanded mode, because of the fault current limiting capability of the inverters from the power sources, when high impedance faults occur at any of the PD3 load branch, overcurrent protection may fail to operate.

Additional tripping criteria: By comparing the current variations between different PD3 branches, coupled with the voltage depression criterion, it is possible to identify which branch is at fault and isolate the faulty PD3 branch correctly.
The Ethernet ring is used to link the MMC and the protection devices. Each protection device reports the information at its location, such as voltage, current, circuit breaker status, fault judgement etc. The device also listens to the information from other sources, thus forms a better understanding of the operation states of microgrid.

- Under islanded mode of operation, when a three-phase fault occurs, the voltage at the busbar will be reduced significantly, the fault current at the faulted line may not be high enough to trigger the overcurrent protection.
- However, the voltage depression criterion together with the current information from the other branches will be able to identify the fault correctly, as discussed in the previous section. Therefore, through information sharing with the other branches, correct discrimination can be achieved.
Thank You! Any Questions?