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LVDC-Redefining Electricity
First International Conference on Low Voltage Direct Current

New Delhi, India,
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Enabling an LVDC last mile distribution network

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Overview

1. Issues with an existing LVAC last mile network
2. Moving to an LVDC last mile: motivations
3. Moving to an LVDC last mile: challenges
4. Protection challenges
5. Protection solution
6. Conclusions
1. Issues with existing LVAC last mile

- Operates at 60-70% of their limits with losses 3%
- Distribution networks are aging
- Benefit the least from load diversity
- Under pressure to host more renewables
- Requires AC-DC conversion for supplying DC loads and hosting renewable
- Become a bottleneck to connect further EV and heat pumps, power flow could reach up to 130%-150% in future UK system
- Under pressure to host more heat and transport demand

[Diagram shows a distribution network with houses and solar panels, indicating the challenges and solutions related to LVAC systems.]
2. LVDC last mile: motivation

**Potential benefits for DSOs**

- Reduced losses and increased power capacity
- Better control of peak demands
- Addressing the technical constraints (enhanced voltage profile, limited impact of the inductance, no skin effect, etc.)
- Release additional generation and demand headroom, and defers reinforcement
- Flexibility in operation offers more flexible market mechanism with better stimulation of customers control demands
- Suitable and powerful ICT platform for integrating various smart grid functionalities
- Supporting better controls, and easier to connect multiple sources
- No phase balance and synchronisation issues
- Reduced fault level and allow the use of lower current ratings and smaller footprint
2. LVDC last mile: motivation

Potential benefits for DSOs

Selected projects of DC in distribution

- ScottishPower £15m ANGLE – DC project
- KEPCO aims to replace a number of existing AC rural MV distribution networks supplying light loads by LVDC networks to save up to 5% of the total operating cost
- Real rural LVDC network as a part of Finnish national Smart Grids research programme

P. Muutinen et al. “Experiences from use of an LVDC system in public electricity distribution” CIRED 2013
2. LVDC last mile: motivation

Potential benefits for end-users

- Reduced energy waste and losses by reducing AC-DC conversion stages
- Power converter interfaces are more mature and their associated costs are declining
- Better control of energy leads to better market services and consumers cost savings
- More suitable for devices generate and consume DC (80% of todays load are DC)
2. LVDC last mile: motivation

- Section 4: Recognised standards of d.c. power distribution over telecommunications cabling
- Section 5: Proprietary d.c. power distribution over telecommunications cabling
- Section 6: Proprietary d.c. power distribution over proprietary cabling
- Section 7: Proprietary d.c. power distribution over conventional single phase a.c. power supply cabling
- Section 8: Proprietary d.c. power distribution over conventional 3-phase a.c. power supply cabling

Verification of existing a.c. power supply cabling
Capability assessment
Implementation
Co-existence issues
Labelling
Certification Protocol
If we are designing the first last mile today, would be an AC or DC?
3. LVDC last mile: challenges

- Very limited experience
- Huge investment in AC
- Interaction with existing AC grid
- Lack of standards (topology, voltages, cable connections, etc.)
- International systematic approach on LVDC not yet provided
- LVDC benefits versus the cost
- Existing LV protection is too simple and not capable of enabling the potential benefits afforded by LVDC last mile networks
Protection is top priority of any electrical distribution system.

**Does DC protection require more caution?**

- Characterisation of DC faults
- DC protection for safety challenge
- The requirement for high speed DC protection
- Detecting and locating DC faults challenge
- Protection against DC voltage disturbances
- DC faults interruption challenge
Characterisation of DC faults

The traditional methods used for DC fault calculations:

- Static mathematical model
- Mathematical model implemented in some ANSI/IEEE guidelines
- IEC 61660-1 dynamic mathematical model

IEC 61660 mathematical model

\[ i_1(t) = i_p \frac{1-e^{-t/\tau_1}}{1-e^{-t_p/\tau_1}} \quad 0 \leq t \leq t_p \]

\[ i_2(t) = i_p \left(1 - \frac{t}{t_p}\right) e^{-\frac{t-t_p}{\tau_2}} + \frac{t_k}{t_p} \quad t \geq t_p \]

Q: Is IEC 61660 suitable for characterising LVDC short circuit currents under all possible system configurations?
### DC protection for safety challenge

<table>
<thead>
<tr>
<th>Band II (LVDC)</th>
<th>Band I (ELVDC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1500V</td>
<td></td>
</tr>
<tr>
<td>400V</td>
<td></td>
</tr>
<tr>
<td>200V</td>
<td>120V</td>
</tr>
<tr>
<td>60V</td>
<td>30V</td>
</tr>
<tr>
<td>0V</td>
<td></td>
</tr>
</tbody>
</table>

- **Dangerous and could kill in case of direct contact**
- **Comparable safety margin can be provided only with 3-wire system with grounded middle point**
- **Comparable safety margin as for AC for direct contact (IEC60479) can be provided in 2-wire & 3-wire systems**
- **For <30V and in normal dry conditions for <60V, basic protection is not required for SELV and PELV systems**

**Protection for safety:** RCDs are not widely and commercially available for DC

**Protection for equipment:** detecting, locating, and interrupting DC faults are challenging

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*The IEC 23E/WG2 workshop, “DC distribution system and consequences for RCDs”*
DC protection for safety challenge

How does DC influence the existing earthing systems?

3-wire DC systems can have lower touch voltages
The requirement for high speed

- Power electronics poor short circuit capability
- DC current circulates in the converter and other sensitive equipment
- Protection systems need to be very fast to
  - prevent a high transient and steady state DC currents from damaging equipment
  - prevent the main converters from losing control and unnecessary tripping; and
  - reduce the impact of post-fault power quality and stability
Detecting and locating DC faults challenge

- The natural small DC line impedances can lead to more complexity for locating DC faults
- Resistive faults hard to detect

Solutions

- Using differential protection (time synchronisation issue)
- Using signal processing techniques-based protection such as Travelling waves and Active Impedance Estimation (AIE)
Protection against DC voltage disturbances

Rapid DC voltage drop

- Fast propagation of voltage disturbance
- Sensitivity of AC/DC and DC/DC to voltage drops

Overvoltage on the DC side

- caused by a line-to-earth fault on the AC side
- Caused by the loss of the supply DC neutral/earth of a bipolar DC system
- Post-fault transient overvoltage due the release of substantial energy stored in the inductor \( \left( \frac{1}{2} LI^2 \right) \) due slow protection

Voltage surge protection or fast protection that reduces the fault duration and magnitude are required
DC faults interruption challenge

- DC arcs are more aggressive than AC
- DC fault without zero crossing do not provide a natural low point to extinguish the fault arc
- More complex techniques such as increased arc length and arc splitters are required
DC faults interruption challenge

Mechanical breakers complied with IEC 60947-2

- LVAC Moulded Case CBs and Miniature CBs (magnetic trip units to be adjusted for DC)
- DC CBs equipped with permanent magnetic
- DC CBs equipped with electronic trip units
- Lower DC current and voltage ratings compared to equivalent AC due to the higher risk of fire in DC

DC solid state breakers

- 900 times faster than LVDC mechanical breaker
- On-state losses issues

Using different converter topologies

- Full bridge DC/DC chopper
- full-bridge Modular Multi-level Converters

DC hybrid breakers????
5. Protection solution

Multi-function DC protection for enabling an LVDC last mile

Features

Communication-assisted
Fault detection and locations are based on DC current directions and magnitudes, and DC voltages
Using multiple IEDs
Using solid state circuit breakers for interrupting DC faults
LVDC testing facilities
Validating the concept
Validating the concept

Start

Measure I & V & Vdc at each IED

The fault is located at the PCC, the AACB is tripped and all downstream generators are tripped

The end user is faulted and its local SSCB directly operates

The fault is on the main feeder, and its IED trips the associated SSCB, and remotely trips all the generators connected to the feeder

I & V within the nominal limits

The converter IED current direction is (+) and the feeder IED is (-)

Any of the customers IEDs has a current with (+) direction

NO YES

NO YES

NO

NO

YES

The IED feeder with (+) current direction takes the lead

The fault is temporary

Reclosing function is performed and loads are energised

End

Measure | I mag and dir & Vdc at each IED

Deployment of the Algorithm using LabVIEW

Actual experiment setup
Experimental results
6. Conclusions

- LVDC distribution systems have the potential to bring benefits to future electricity grids.
- Replacing or energising an existing part of AC circuits using DC is still at very early stages and limited by practical technical solutions and lack of standards.
- The fund to LVDC projects is still limited to national levels.
- Protection and safety one of the major concerns.
- The developed fast acting DC protection has demonstrated more resilient performance for future LVDC networks.
Thank you & Q