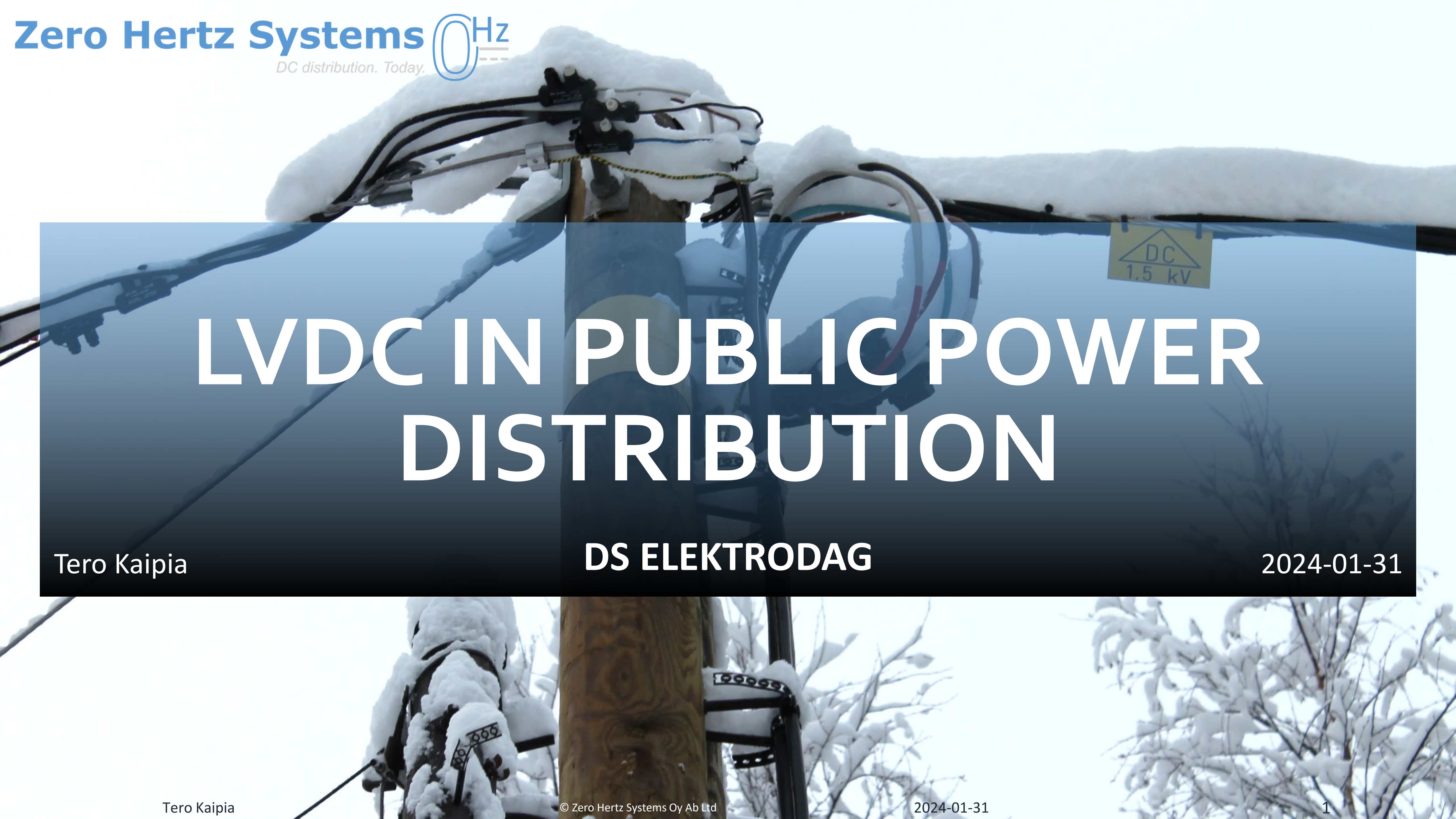


LVDC IN PUBLIC POWER DISTRIBUTION

DS ELEKTRODAG

Tero Kaipia

2024-01-31

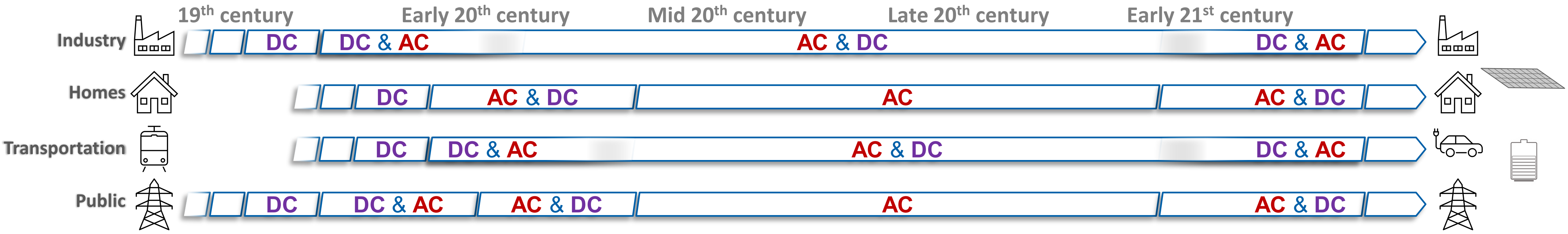
DC NEVER DIED

THE WAR OF CURRENTS IS NOT OVER!

1870s – 1880s
Dawn of electricity distribution
- ”Edisonian” DC systems dominate!

By 1930s
The first battle is over
- Cities widely electrified with AC
- AC is used in almost all new installations
- DC remains in use in industry, traction systems and in older installations

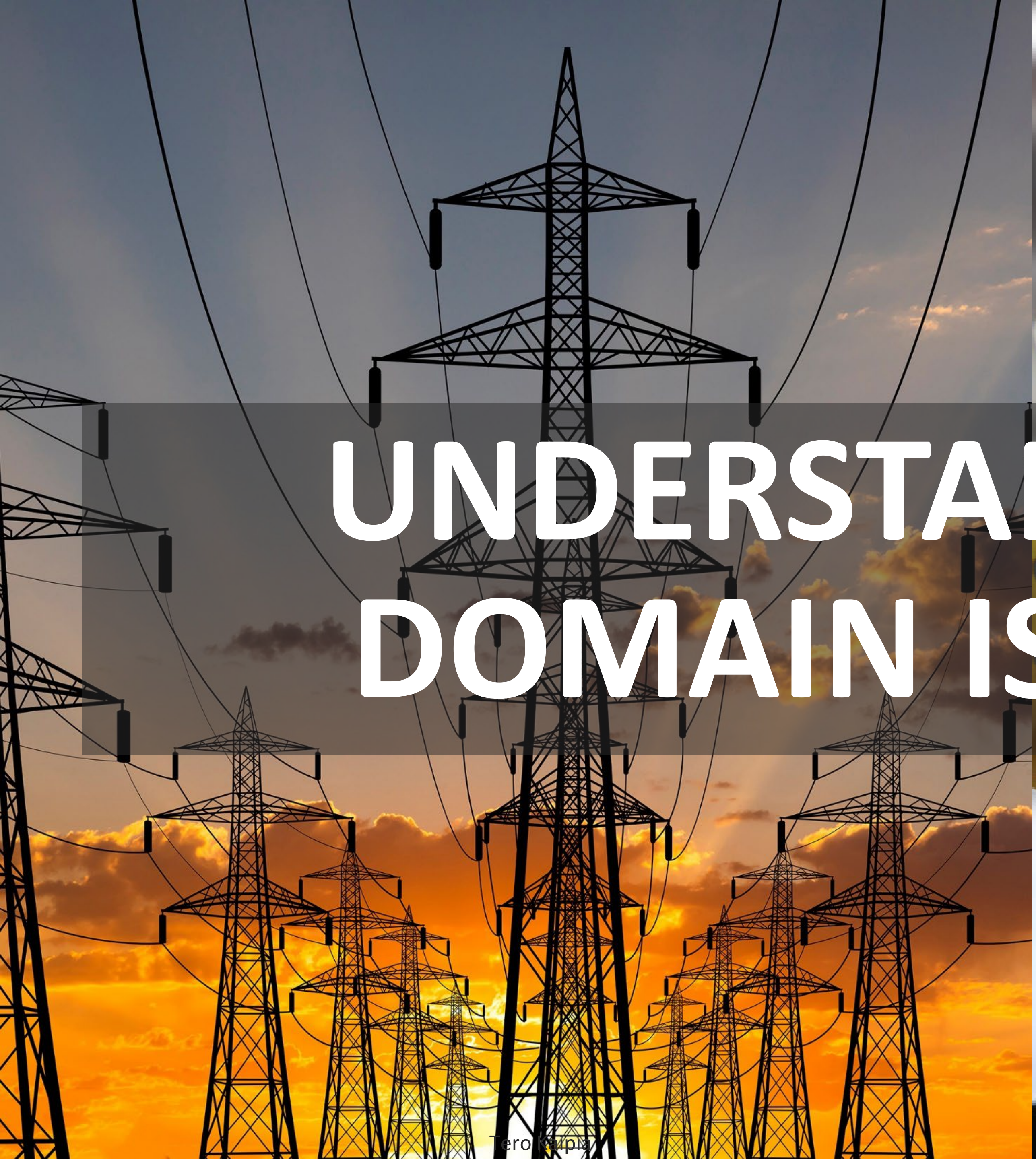
Late 1990s – early 2000s
Return of the old rival
- Modern power electronics enables DC systems with supreme controllability
- Growing shift to DC-based production and consumption



1890s
A Challenger emerges
- 3~AC proves its supreme controllability and effectiveness
- Wider-scale power distribution becomes possible
- War of currents is declared!

1950s – 1960s
Wide-scale expansion and centralisation
- Last old DC systems are largely replaced with modern AC systems
- DC remains in use in industry, traction systems

2020s –
Era of decentralisation and growing electricity dependence
- Hybrid AC/DC system challenges the domination of AC
- AC and DC coexist again, but now AC starts to appear outmoded!

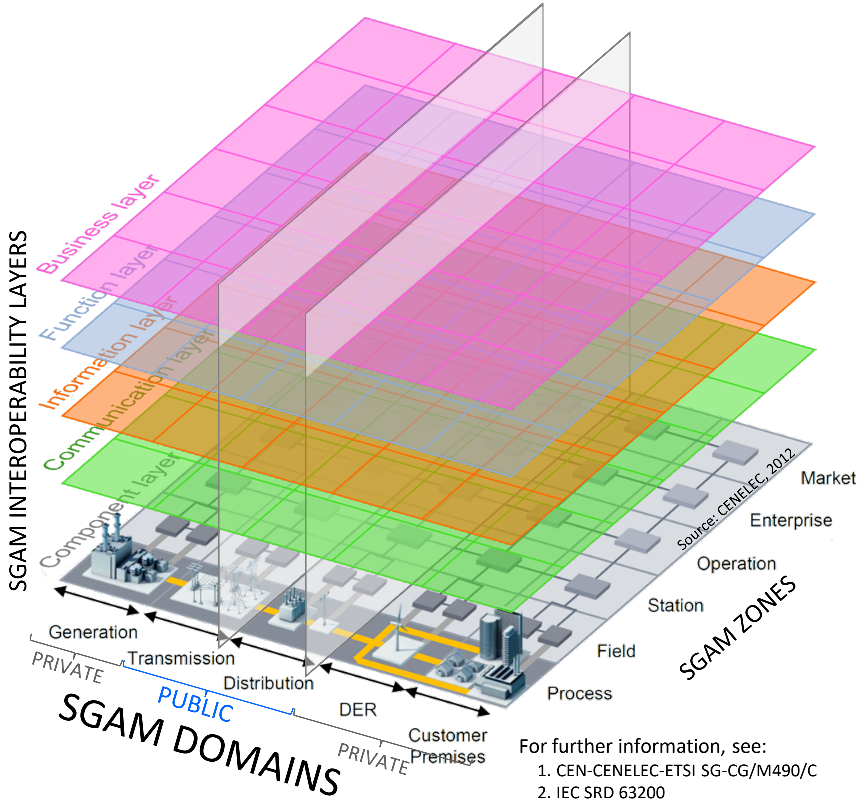


UNDERSTANDING THE DOMAIN IS CRUCIAL!

DOMAIN DEFINITION

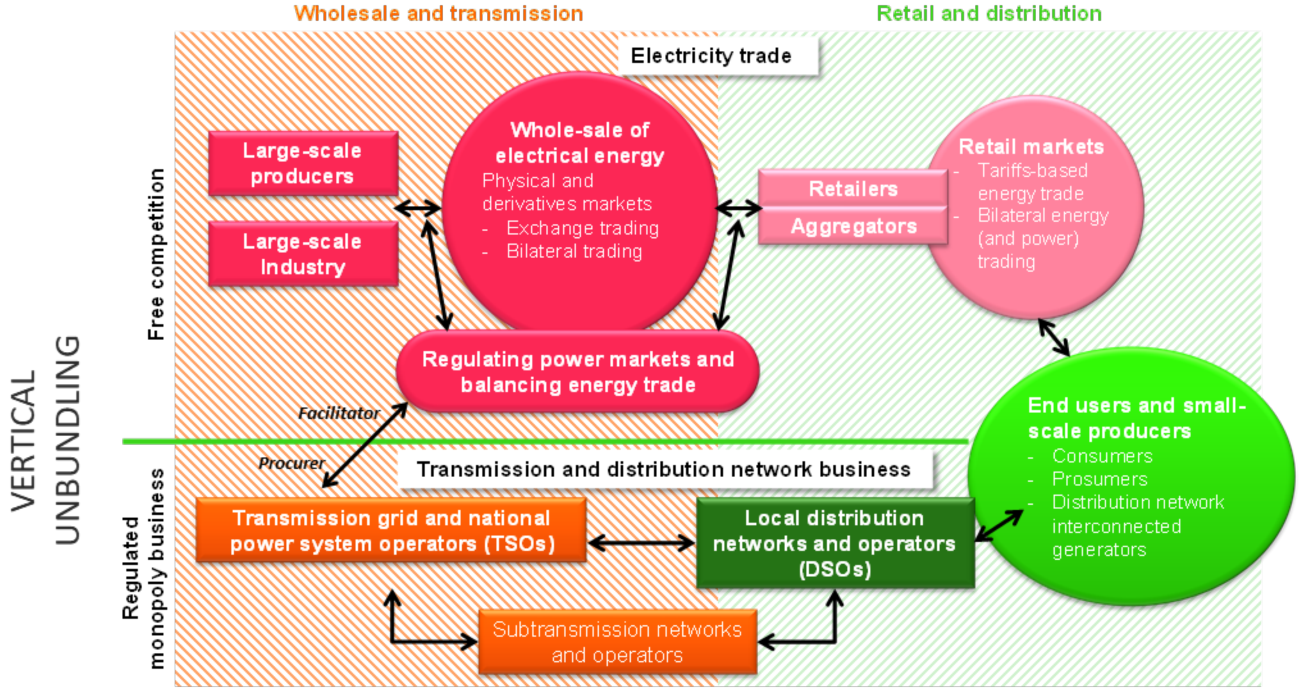
PUBLIC DISTRIBUTION

ORGANISATION OF THE ELECTRICITY SECTOR



For further information, see:

1. CEN-CENELEC-ETSI SG-CG/M490/C
2. IEC SRD 63200



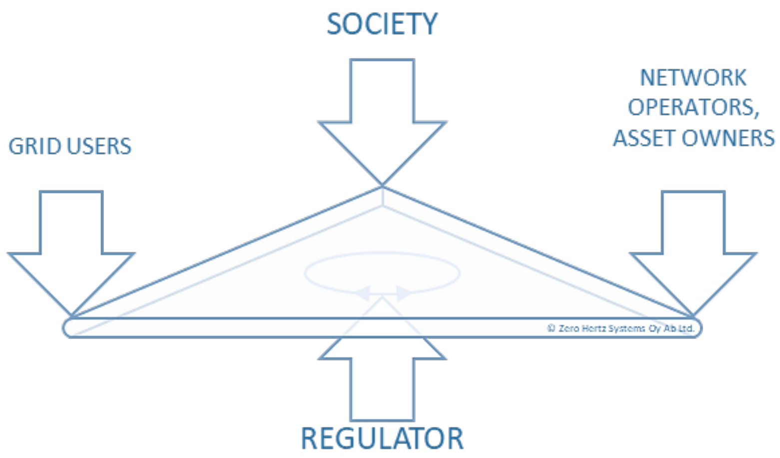
Basic structure of the Nordic Electricity Markets
Adapted from an illustration by Reima Päivinen, Fingrid Oyj, 2012

*"**DISTRIBUTION** means the transport of electricity on high-voltage, medium-voltage and low-voltage distribution systems with a view to its delivery to customers, but does not include supply"* (2019/944/EU)

DOMAIN DEFINITION
PUBLIC DISTRIBUTION

DNOs / DSOs are public utilities regardless of their ownership structure or type of organisation

- Business is based on management of public infrastructure in public space
  - Business is conducted as local “natural” monopoly in designated service areas
- Business case is to provide a publicly available electricity network service that enables subscribers to access the electricity markets
  - Anyone is entitled to a network service subscription, connection and access to the network without discrimination
- Business is strictly regulated and subject to authority license and supervision
  - Business role is limited by legislation and activities supervised
  - Pricing of network service fees is determined by a regulated methodology



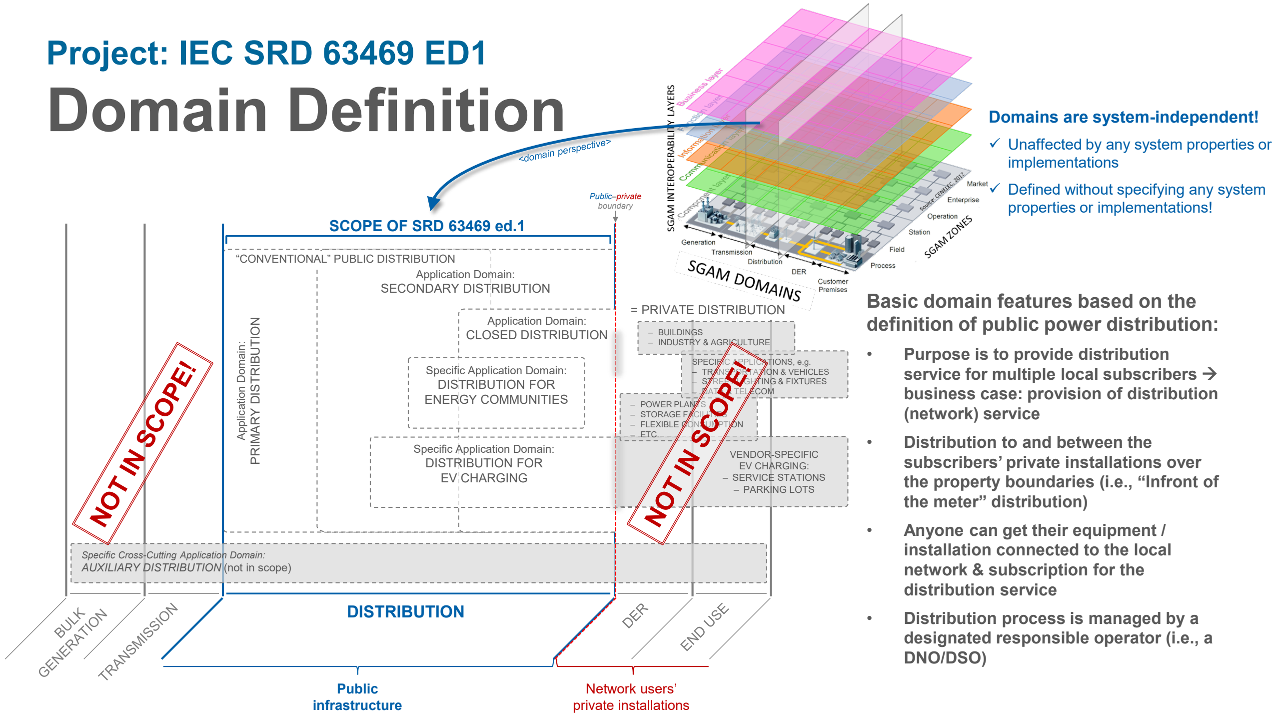
- ❑ Obligation to serve and treat equally
- ❑ Obligation to develop and maintain
- ❑ Obligation to connect, transmit and measure
- ❑ Etc…

- ❑ Reasonableness of pricing
- ❑ Reasonableness of profit and ROI
- ❑ Life-cycle cost-effectivity of investments
- ❑ Operational efficiency

DOMAIN DEFINITION

OTHER ASPECTS TO CONSIDER

- Societal roles and expectations related to the domain
- Interdependencies and interaction between neighbouring domains
- Established (legacy) practices related to business and system implementation
- Physical environmental conditions and their impacts on actors’ operations and system characteristics
- Skill levels of people using, operating, building and maintaining the systems belonging to the domain



CHALLENGES

OF PUBLIC DISTRIBUTION

- Energy transition and societal criticality of power distribution
- Growing importance of tail-end distribution networks for entire power system
- Aging network infrastructure and urgency of redevelopment for modern needs
- Socio-economic affordability and business profitability of development actions
- Societal, political and regulatory pressures

SUPPORT

TRANSITION TO CLEAN ELECTRICAL ENERGY SYSTEM

MODERNISE

NETWORKS AT LOW COST AND PROFITABLY

PROVIDE

HIGH QUALITY NETWORK SERVICES COST EFFECTIVELY

CHALLENGES AND OBJECTIVES

OF DISTRIBUTION NETWORK OPERATORS

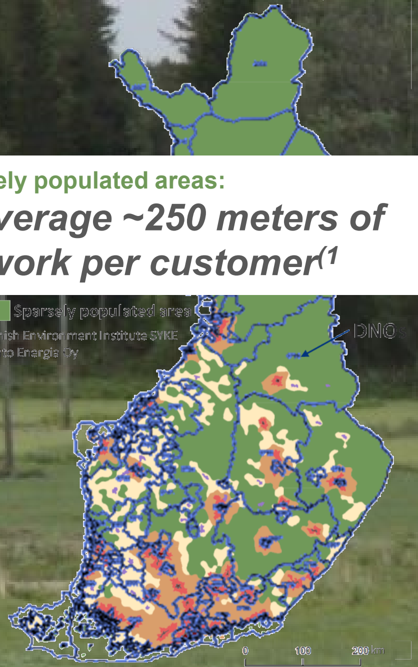
- Increasing nonlinearity, coincidence and peak power of loads
- Insufficient network capacity and increasing power quality problems
- Need to ensure high network service availability and quality
- Extent and speed of needed network development activities
- Uncertainties in longevity of development actions taken
- Affordability, financing and profitability of network development investments

Share of distribution system investments 70% of all grid investments

DNOs' CHALLENGES – SPECIFIC EXAMPLE
SPARSELY POPULATED AREAS

- Long and aging overhead line networks in harsh environmental conditions
- Security of supply problems caused by weather phenomena
- Strict regulatory limits for the availability of network service
- Depopulation and declining round-the-year habitation
- Low energy consumption but occasionally high peak power
- Maintaining profitability of distribution business whilst renewing the network

Sparsely populated areas:
In average ~250 meters of network per customer[1]



[1] *Statistics of Finnish Energy Authority for year 2019*

CASE FINLAND

Most of the distribution network infrastructure exists to serve customers outside urban areas!

DNOs’ EXPECTATIONS FOR LVDC

Enable…

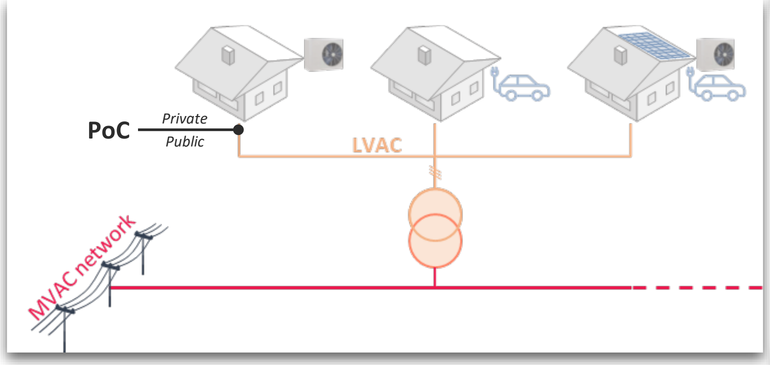
- Maximisation of transmission capacity of secondary distribution networks
- Improvement of availability network service and security of supply
- Guaranteeing conformity of quality of voltage supplied to subscribers
- Implementation of dispersed control of MVAC voltage and reactive power flows
- Mitigation of distortive current flows and interference propagation
- Evolution of network automation and data-based condition management

And to enable all of these to be realised…

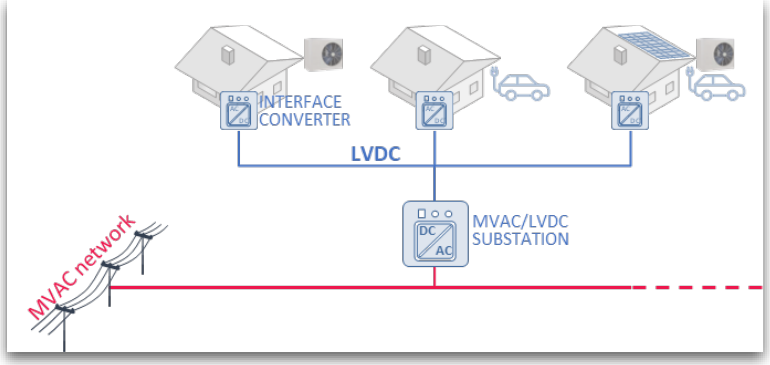
- **More life-cycle cost-effectively than by sticking to pure AC networks**
- **Without compromising subscribers’ access to any electricity market**

LVDC IN SECONDARY DISTRIBUTION
BASIC DEPLOYMENT OPTIONS

CONVENTIONAL LVAC DISTRIBUTION

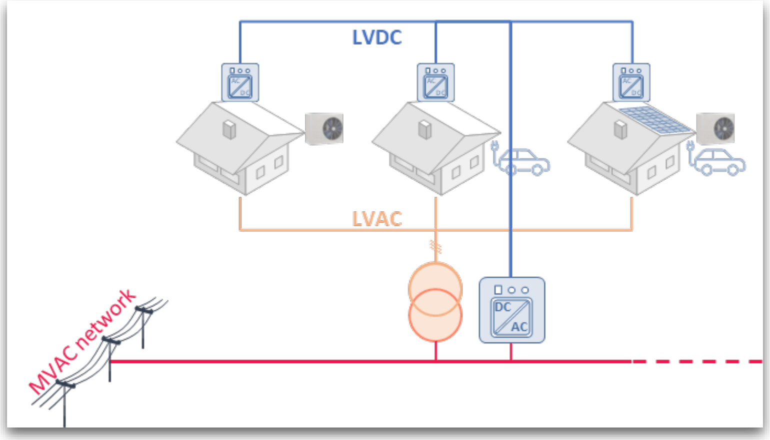


- DNO's area of responsibility ends at the point of connection (PoC) of subscriber's installation



REPLACEMENT

- LVDC network is used to replace existing LVAC network, completely or partly
- Secondary network is rebuilt, or when possible, existing LV cables are converted to LVDC use (if type, condition and age allow)
- Nothing needs to be changed on subscribers' side, DNO can focus solely on development of its own network.



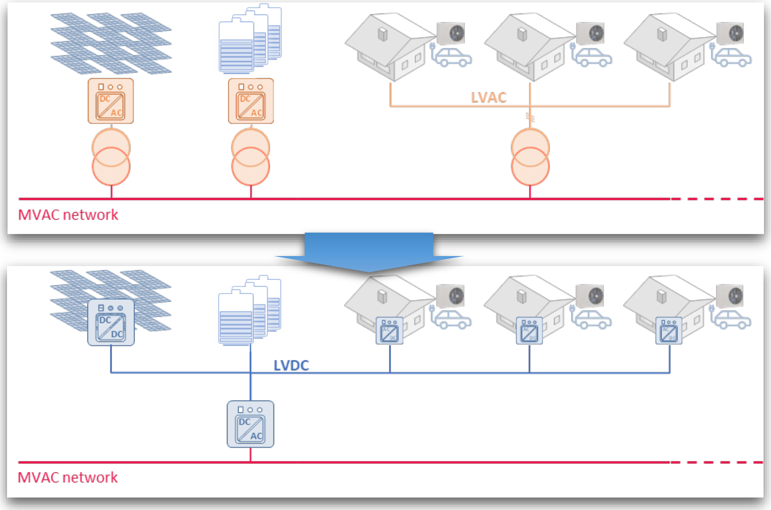
PARALLEL NETWORK

- LVDC network is implemented as parallel installation, secondary network is doubled
- Existing LVAC networks can remain unchanged and be renovated / developed separately
- Subscriber-end loads can be divided between parallel networks, physically (fixed) or logically (dynamic)
- Physical partition of loads requires two PoCs and related changes in subscribers' installation

LVDC IN SECONDARY DISTRIBUTION

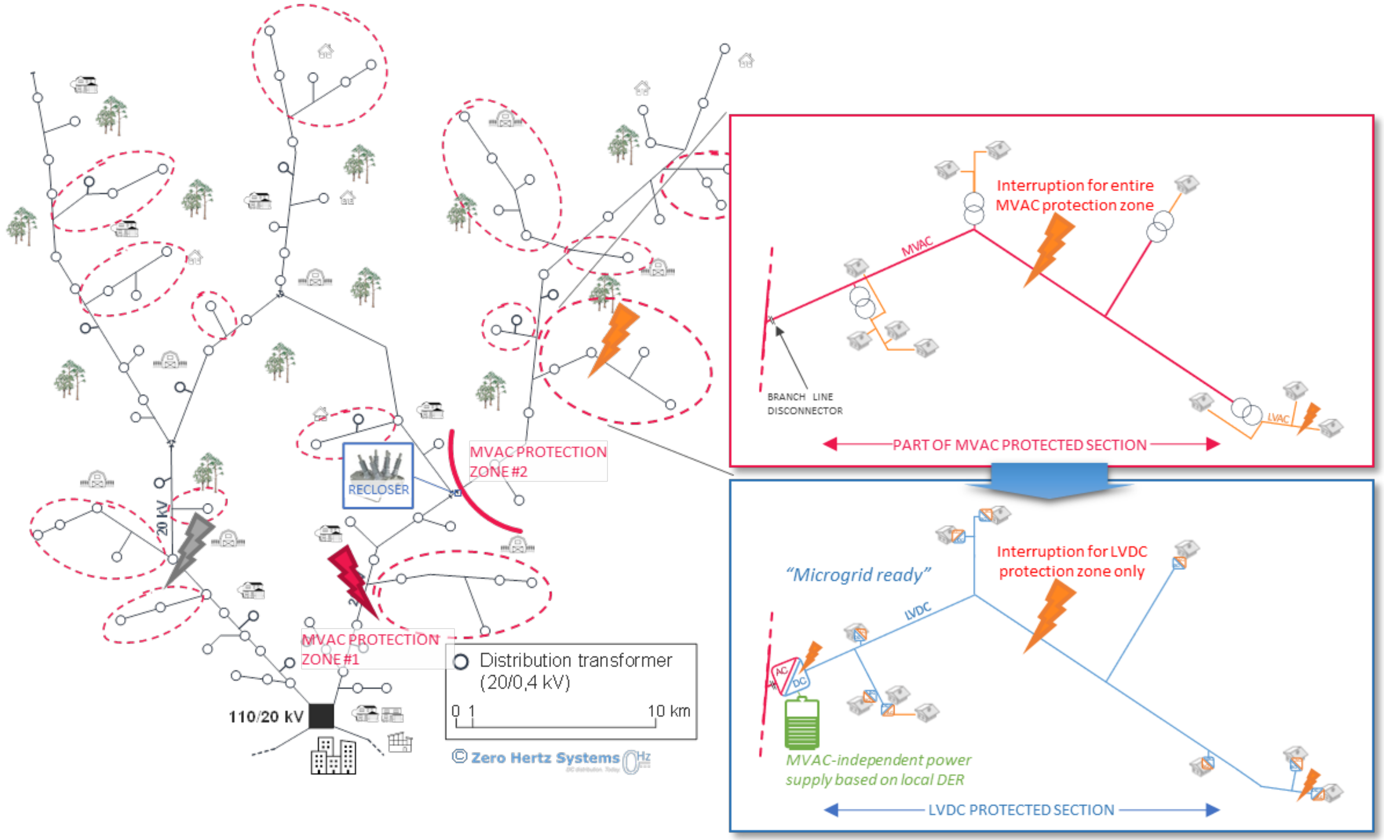
OTHER EXAMPLES OF USAGE

Reduction of secondary substations



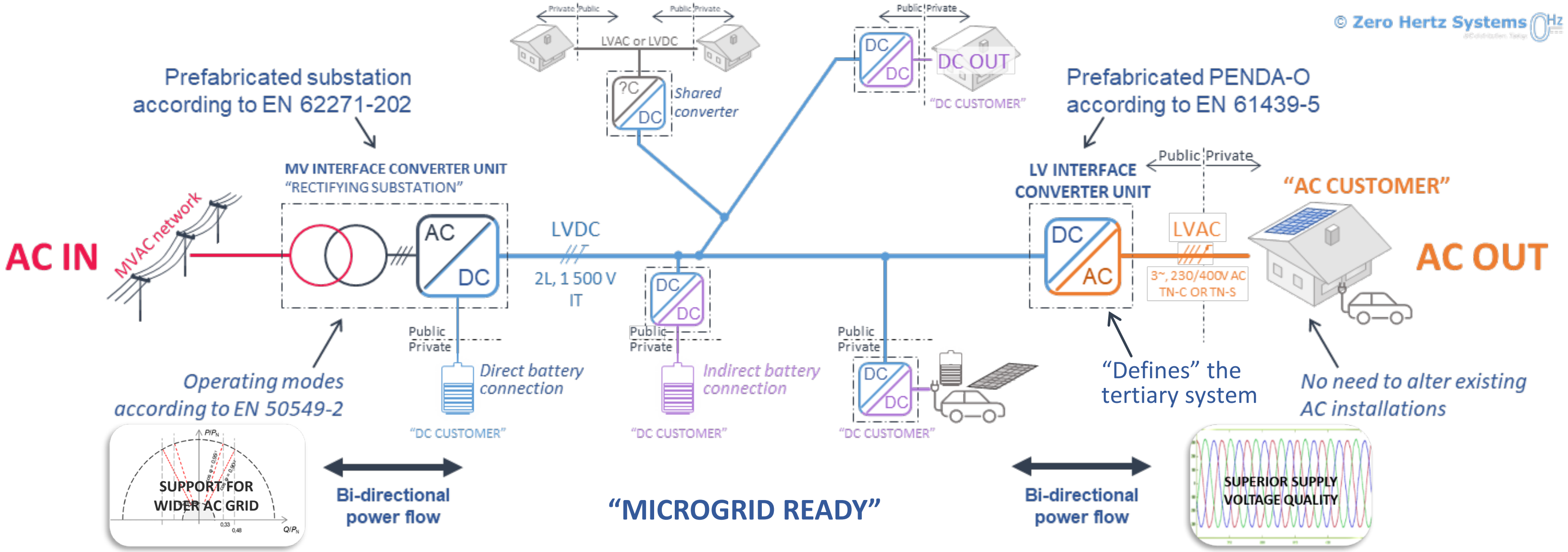
- Land use optimisation
- Network topology simplification
- Security of supply improvement
- Overall cost minimisation

Reduction of MVAC branch lines



LVDC IN SECONDARY DISTRIBUTION

MAIN SYSTEM PROPERTIES



Highest allowed voltage for operation and equipment [V]	Highest voltage for temporary operation [V] (+10%)	Highest voltage for continuous operation [V] (+6%)	Nominal voltage and rated voltage of equipment [V]	Lowest voltage for continuous operation [V] Preferred (−10%)	Lowest voltage for continuous operation [V] Supplementary (−15%)	Lowest voltage for temporary operation [V] (−20%)	Lowest allowed voltage for operation and equipment [V]
1700	**1650**	**1590**	**1500**	**1350**	**1275**	**1200**	**1060**
870	825	795	750	675	640	600	530
Emergencies	Exceptional loads	Normal loads				Exceptional loads	Emergencies
Immediate OV trip if above	Allowed voltage variation under normal operating conditions						Immediate UV trip if below

- Intermediate distribution level between MVAC network and grid users' installations
- Based on modern industrial DC systems and equipment
- Designed to…
  - Maximise transmission capacity of LV networks
  - Function like traditional network equipment
  - Integrate fully with DSOs' SCADA systems
  - Comply with existing EN and SFS standardisation

1 500 V LVDC DISTRIBUTION

COMPATIBILITY ACROSS APPLICATION DOMAINS

PUBLIC DISTRIBUTION

±750 / 1500 V

Maximum transmission capacity and compatibility with both traditional and modern DC voltages used today in several key applications from industrial drives to BESS facilities and PV power plants.

Good commercial availability of applicable and already standardised products, including essential components like power cables and protection devices

"Edisonian" DC voltages

Historical DC voltages compatible with the nominal cell voltage of flooded Pb acid batteries

220, 440 V

ELV BAND: 12, 24, 48, 96, 110 V

Conventional industrial DC voltages

Traditional DC motor and generator voltages used in industrial DC drive systems. Typical voltages of common DC buses supplied with thyristor rectifier from 3~, 50 Hz, 380–400, 500–525 or 660–690 V AC grid are underlined.

125, 220, 250, 440, 500, 550, 600, 750

DC traction systems

Standard DC voltages used in traction systems, both to supply trains, trams and trolley busses as well as in internal mains distribution in trains.

600, 750, 1500, (3000) V

Modern industrial DC voltages

Typical common DC bus voltages of modern industrial drive systems equipped with an active front-end grid inverter connected to 3~, 50 Hz, 400, 500 or 690 V AC supply

600, 750, 1000 V

Grid-connected BESSs

Nominal voltages of stationary battery energy storages. Certain voltages have become more typical due to their compatibility with industrial grid inverters and cell voltages of popular Li-ion chemistries.

640–660, 720, 750, 780, 1000, ..., 1500 V

EV and DC charging voltage

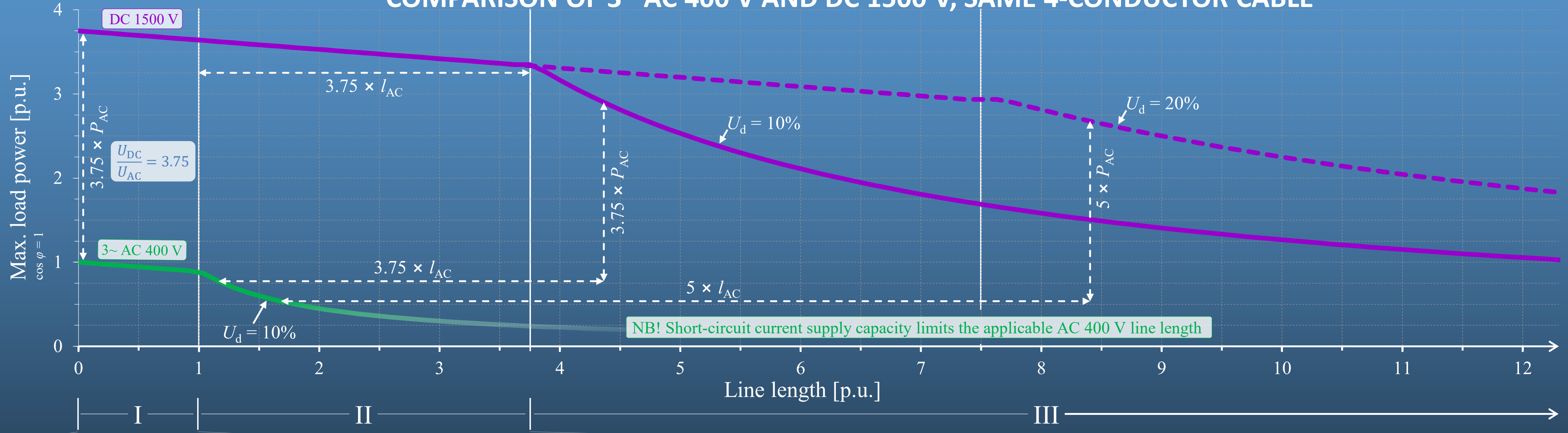
Nominal EV battery voltages (cars, busses, trucks) and DC fast charger output voltages common today. There is a lot of small variation in nominal battery voltages between brands and even between the products of a manufacturer. The tendency is still towards higher battery voltages and the next step may be 1250 V for heavy trucks.

200–1000 V (400, 600, 800, 900, 1000 V)

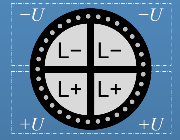
1500 V LVDC DISTRIBUTION

TRANSMISSION CAPACITY

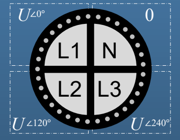
COMPARISON OF 3~ AC 400 V AND DC 1500 V, SAME 4-CONDUCTOR CABLE



Cable connection in DC use



Cable connection in AC use



I Line length ≤ 1 p.u.

In this range, the transmitted load power is limited by the maximum thermal current carrying capacity (thermal load capacity) of the cable in both AC and DC use. When operated at the thermal load limit, the power losses in the cable are equal. Conversion to DC 1 500 V increases the transmission capacity by at least a factor of 3.75 and the coefficient grows slightly along with the line length.

II Line lengths 1 p.u. – 3.75 p.u. (1 p.u. – 7.5 p.u.)

In this range, the load power is limited by the voltage drop in AC use and the thermal load capacity in DC use. The longer the line length, the more the conversion to DC increases the usable transmission capacity, approaching a coefficient of 3.75^2 (≈14) as the line length approaches a value of 3.75 p.u.

If twice the relative voltage drop is allowed in DC use compared to AC use (e.g. 20%), range II extends to a line length of 7.5 p.u. and the increase in transmission capacity approaches a factor of 25.

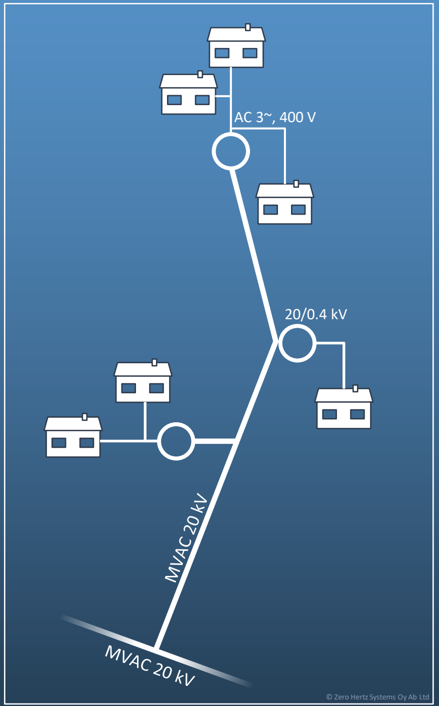
III Line lengths >3.75 p.u. (>7.5 p.u.)

In this range, the load power is limited by the voltage drop in both AC and DC use. Furthermore, at AC 400 V the cable length is limited by short-circuit current supply requirements. If the allowed relative voltage drop is the same for both AC and DC use, the transmission capacity at DC 1500 V is 3.75^2 (≈14) times higher than at 3~ AC 400 V, i.e., 3.75 times more power can be transmitted 3.75 times further away.

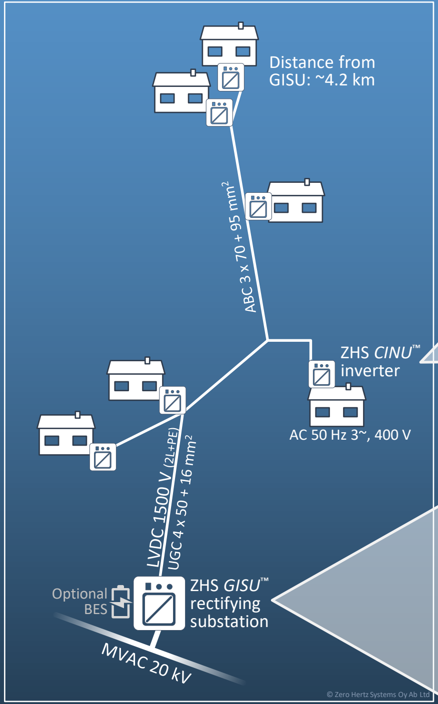
If twice the relative voltage drop is allowed in DC use, the transmission capacity coefficient is 25, i.e., 5 times more power can be transmitted 5 times further away compared to 3~ AC 400 V.

INSTALLATION EXAMPLE

1.5 kV LVDC DISTRIBUTION NETWORK



Original old AC network arrangements



Constructed new LVDC network (2021)

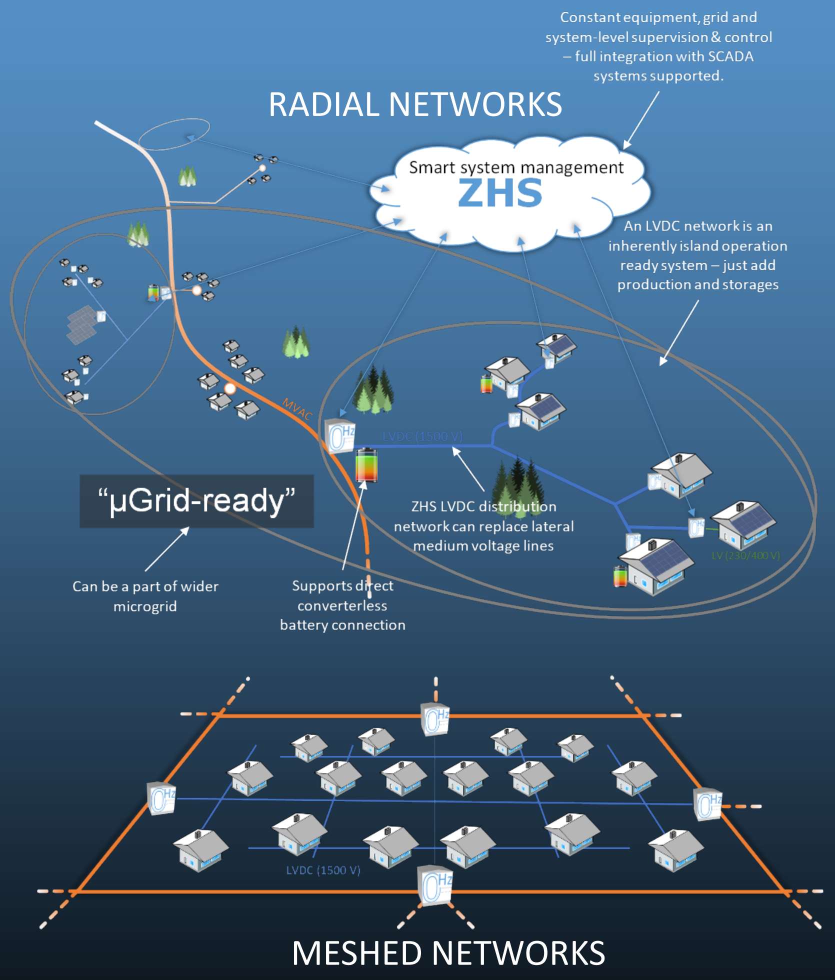
Kymenlaakson Sähkö

ABC = Aerial Bundled Cable (CENELEC HD 626)
UGC = Underground Cable (CENELEC HD 603)

ZHS SOLUTIONS
HybriDCell™ AC/DC SYSTEMS

COST-EFFECTIVE HIGH-PERFORMANCE SOLUTIONS FOR SMART PUBLIC POWER DISTRIBUTION AND UTILITY MICROGRIDS

- Network architecture based on dynamically scalable hybrid AC/DC microgrid cells and intelligent system-level control
- Utilises **1 500 V LVDC technology** to maximise the transmission capacity of low-voltage distribution
- AC in AC out – no changes required into interconnected AC systems, fully **compatible with existing customer-end AC installations**
- Inherent capability of island operation and local power balance management within the constraints of local energy resources
- Full 4Q-operation enables control of AC and DC power flows and voltages – minimises congestion risks and maximises supply voltage quality
- Ready for aggregation of energy resources for electricity market and power system support purposes
- Supports full SCADA integration via standard communication interfaces – enables advanced grid automation and supervision



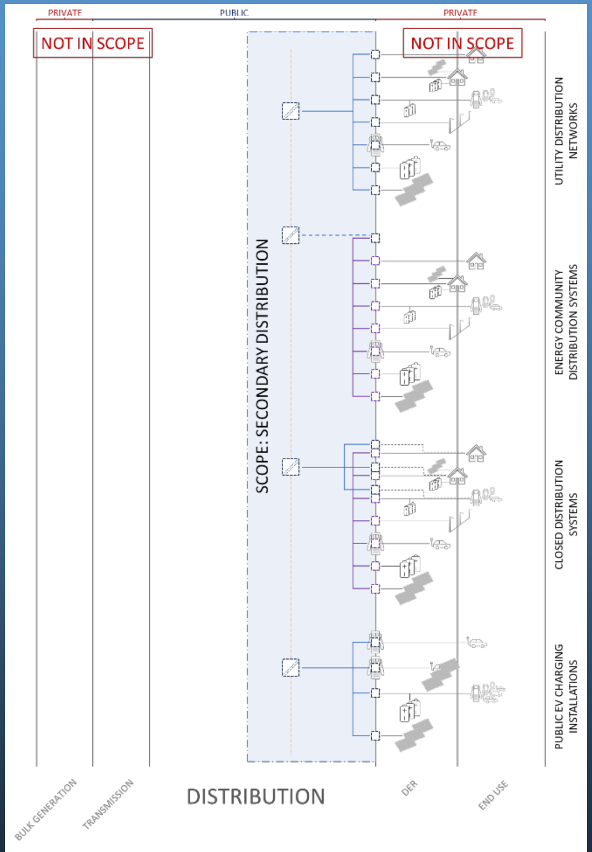
STANDARDISATION ACTIVITIES

IEC SYC LVDC / WG 2

Project IEC SRD 63469 Ed1

Use Case Collection and Analysis: LVDC Systems for Public Electricity Distribution and distribution microgrids

- Project started in September 2022
- Scope covers use of LVDC in public low voltage distribution, including application domains:
  - “Normal” utility distribution networks
  - Energy communities' distribution systems
  - Closed distribution systems (as defined by EC)
  - Public multi-vendor EV charging installations
- CD1 stage circulation for expected during spring 2024



Please contribute your knowledge on system specifications and use cases!

SUMMARY

- Pilots have proven feasibility of LVDC distribution and hybrid AC/DC microgrids in public power distribution
  - Economic viability is expected to improve as market evolve
  - Piloting phase is not over yet: DNOs are waiting for long-term experiences before considering wider adoption
- Most components are well available, but further standardisation is needed
  - Gaps in EMC standardisation must be filled
  - Product standards for converter equipment must be developed
  - System level electrotechnical specifications must be agreed upon
  - Several small gaps and inconsistencies in relevant existing standards must be addressed

WHY LVDC?

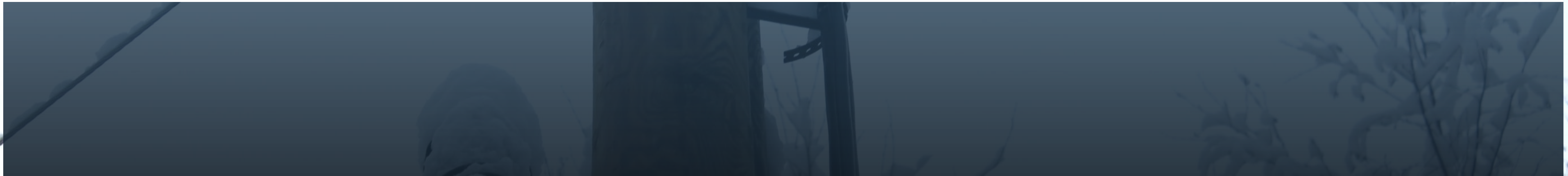
- Existing distribution network needs renovation or expansion
- Investment without development is not an option
- Total cost-effectiveness of network investments is essential
- LVDC distribution offers supreme controllability and capacity-cost ratio

HOW LVDC?

- By replacing old AC network structures with LVDC ones
- By converting existing LVAC networks to LVDC use
- By building parallel LVDC network next to an old AC network

Zero Hertz Systems

Next-Generation Distribution Networks



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