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Technical Specifications + Simplified Connection Criteria

High-level introduction

Overview

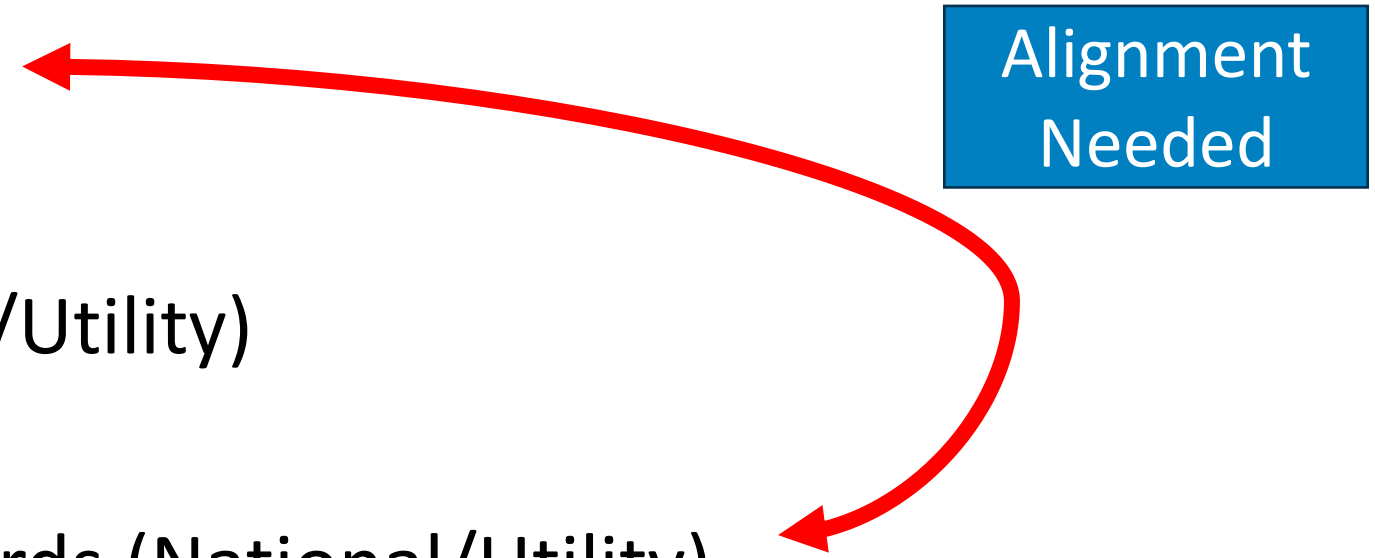
- Introduction
- Technical Specifications
  - Wiring code
  - Interconnection specification
  - Grid Code
- Simplified Connection Criteria

Introduction

- Technical specifications:
  - Overview of type of documents
  - Why?
  - What are key aspects for DG?
- Simplified connection criteria
  - Grid Impact Studies
  - What are they?
- Optional: further work

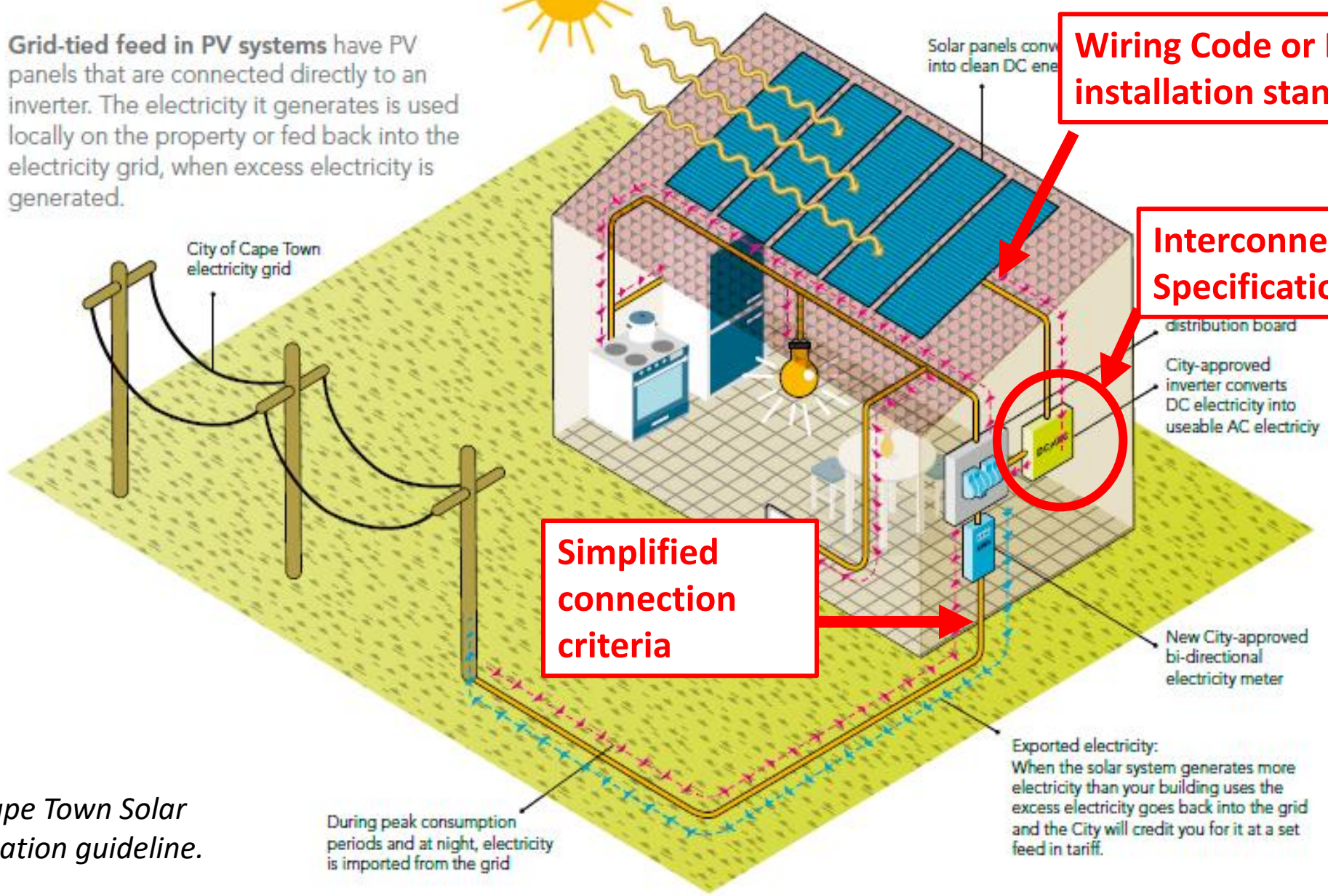
Important Technical Documents

- Grid codes (National)
- Wiring codes (National/Utility)
- Interconnection standards (National/Utility)



01 GRID-TIED FEED IN PV SYSTEMS

Grid-tied feed in PV systems have PV panels that are connected directly to an inverter. The electricity it generates is used locally on the property or fed back into the electricity grid, when excess electricity is generated.



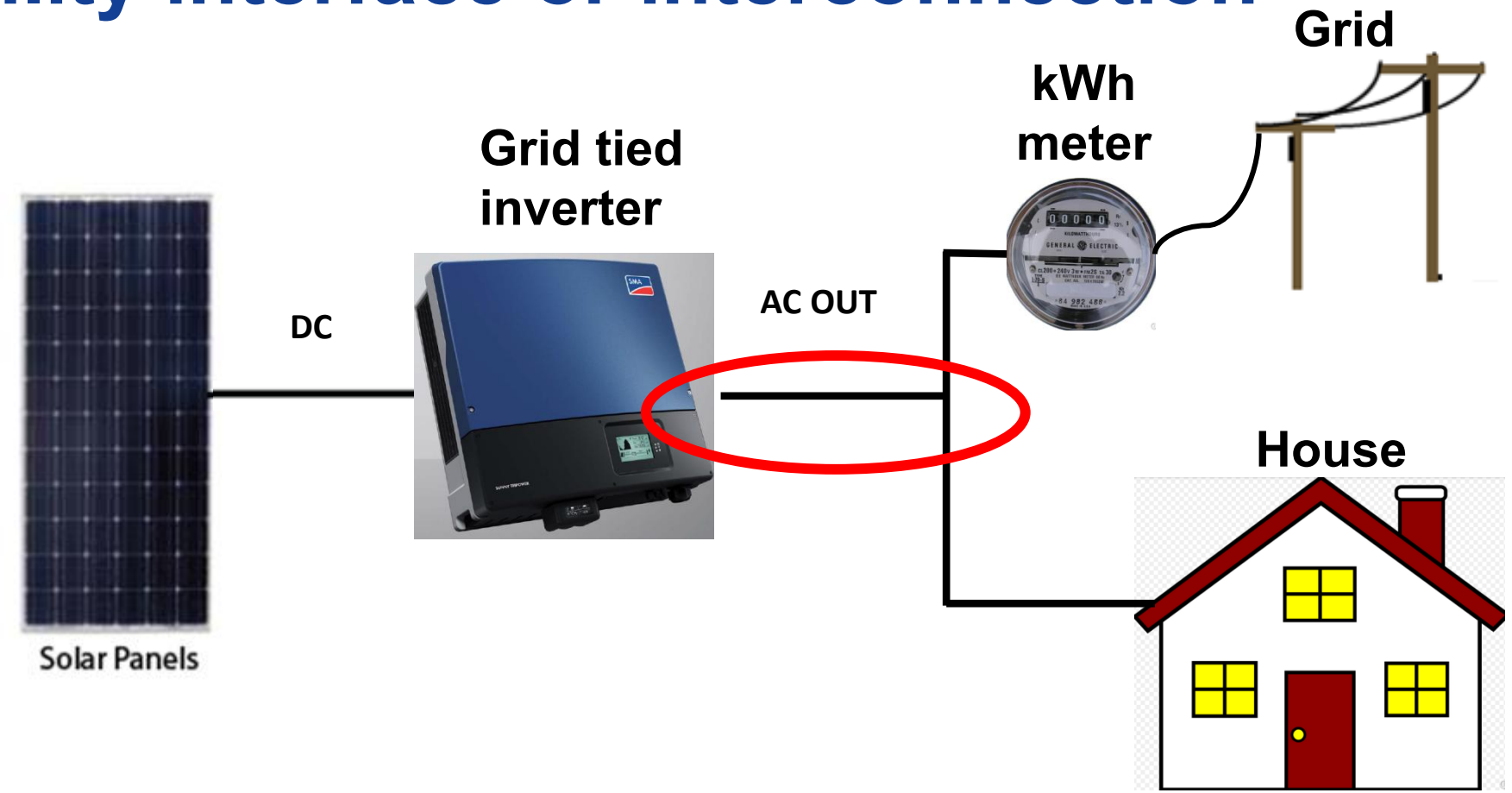
Wiring Code or Electrical installation standards

Interconnection Specification

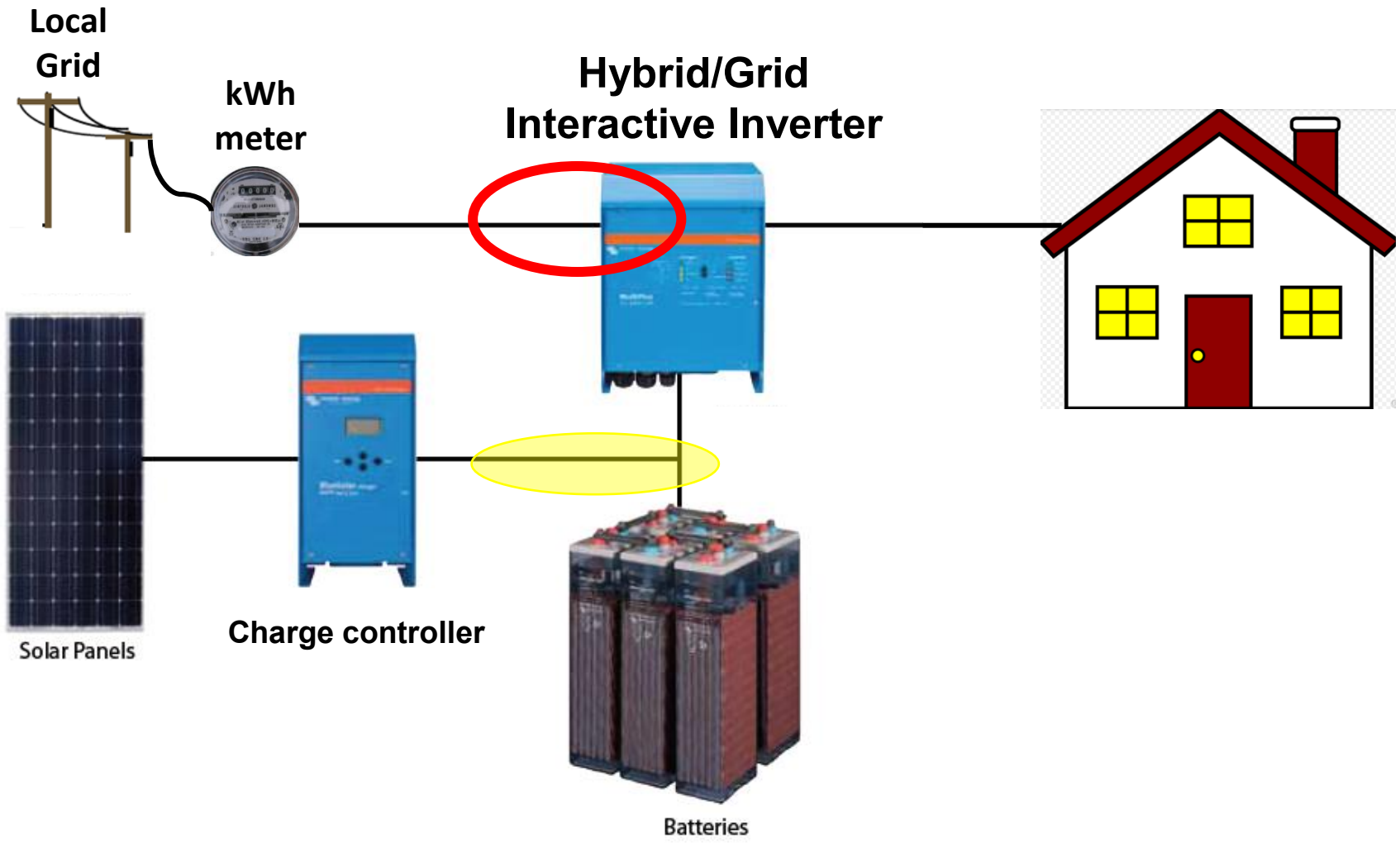
Simplified connection criteria

Source:
City of Cape Town Solar PV installation guideline.

Utility interface or interconnection



Utility interface or interconnection



Grid Code(s)

- Level playing field for all participants
- “Rules of the road” for generators and consumers

- Generation Code
- Transmission Code
- Distribution Code

- IPP or DG Code(s)

TECHNICAL SPECIFICATIONS / STANDARDS

Wiring Code
(Electrical Installation Standards)

Wiring Code (Electrical Installation Standards)

- General Electrical requirements
  - Wire- or cableways
  - Distribution boards
  - Labelling

Wiring Code (Electrical Installation Standards)

- Solar PV specific requirements
  - Equipment standards
  - Earthing and Bonding
  - Protection (Overvoltage, Overcurrent, Reverse current, etc.)
  - Isolation
  - Monitoring
  - Neutral Earth bonding/bridge
  - Location of installation (To be included)

Examples of Wiring Codes - Parts for PV (DG)

- NFPA 70: American National Electrical Code (NEC)
  - Article 690 and article 705
- IEC 60364-series: International set of standards
  - IEC 60364-7-712
- BS 7671: British Requirements for Electrical Installations
  - Chapter 712
- SANS 10142-1: South African wiring code
  - Pending (also adopted IEC 60364-7-712)

TECHNICAL SPECIFICATIONS / STANDARDS

Interconnection Specifications or Standards

Interconnection specifications: Key aspects to cover

- Interface requirements
  - Requirements for the Utility
  - Requirements for the Generator (devices and units)

- Safety
  - Utility
  - Device / generator
  - Installation

- Metering

Examples of interconnection standards

1) **IEEE 1547** – American interconnection requirements for **paralleling distributed** generation (DG) installations with electric power systems.

2) **IEC 61727** International standard requirements **for grid connected photovoltaic** (PV) power systems

3) **EN 50549-series** European Standard specifies requirements for **inverters for grid connected photovoltaic (**PV) systems.

Examples of interconnection standards

4) **VDE 4105** German national standard with requirements for **electronic equipment in low-voltage installations, including inverters for grid connected photovoltaic (PV) systems**

5) **NRS 097-2-series** South African industry specification specifying **utility interface requirements for embedded generation** on the **LV distribution network**.

6) **UK ER G98 / G99** UK specify requirements for **the connection of microgeneration and embedded generation (including solar PV)** to the **distribution network.**

Energynautics' Comparison

Country	Recommendation			NRS097-2-1(2017 Ed. 2.1)		
Type	PPMs					
Categorisation	A1	A2	A3	A1	A2	A3
Size & voltage connection level	(≤ 13.8 kVA) Senegal: ≤ 6 kW	(13.8 kVA < P < 100kVA) Senegal: 6 kW < P < 100 kW	(100 kVA ≤ P ≤ country-specific) Eswatini: 350 kVA Namibia/Uganda: 500 kVA Lesotho/Mozambique/Kenya/Madagascar: 1000 kVA Liberia: 2000 kVA	≤ 13.8 kVA	13.8 kVA< P<100kVA	100 kVA≤ P<1000 kVA
Voltage operating range	Eswatini: -15% to 10% Mozambique/Uganda/Namibia/Kenya/Liberia/Zimbabwe/Senegal: ±10% @ gen. terminal			-15% to 10% The SA RPP Grid Code requirements will override requirements of NRS for this category. For Eswatini, threshold exactly matches.		Based on SA RPP (-15% to 10%) For Eswatini, threshold exactly matches.
Frequency operating range capability – continous operation	49Hz - 51Hz			47Hz - 50.5Hz		47Hz - 52Hz
Frequency operating range capability – abnormal operation	46Hz - 52Hz Senegal: 47Hz - 52.5Hz			not specified		
Rate of change of frequency	Eswatini/Lesotho/Namibia/Uganda/Kenya/Liberia/Zimbabwe: 1 Hz/s for duration of 0.5s Mozambique: 1.5 Hz/s for duration of 0.5s Madagascar/Senegal: 1.25 Hz/s for duration of 2s & 2 Hz/s for duration of 0.25s			n	n	n
Synchronising to the IPS	>60s V @ gen. terminal range: Eswatini -> -15% to 10%, Namibia/Mozambique/Uganda/Kenya/Senegal/Madagascar -> ±10% Freq range: 49-50.2 Hz (Senegal: 49-51 Hz, Madagascar: 48.3-50.5 Hz) For Liberia: after 5mins, V @ gen. terminal range: ±10%, Freq range: 49.8-50.2 Hz			> 60s Synch. Gen.: Δf = 0.3 Hz, Voltage difference: 5 % of nominal voltage per phase, Phase angle difference: 20 degree EG: V@POC range: -15% to 10%, Freq ?		
Disturbance withstand-capability and response (LVRT, HVRT)	y	y	y (also HVRT)	The SA RPP Grid Code will override requirements of NRS for this category.		Based on SA RPP Grid Code. No HVRT
Fast fault current injection (FFCI)	n	n	y (only MV-connected)	n	n	n
Voltage phase jump	To withstand a sudden phase jump of up to 20 degree @ generator terminal			n	n	n
Over-Frequency Response	Eswatini/ Mozambique/ Uganda/Kenya/Liberia/Zimbabwe: y, threshold at 50.5 Hz, disconnect at 52 Hz, droop 4% Madagascar: y, threshold at 50.5 Hz, disconnect at 52 Hz, droop 3%? Namibia: y, threshold at 51 Hz, disconnect at 52 Hz, droop 2.67% Senegal: y, threshold at 50.5 Hz, disconnect at 52.5 Hz, droop 4%			50.5-52 Hz, droop 4% frequency > 52 Hz for longer than 4 s, cease to energise within 0.5 s. For Namibia and Senegal, the thresholds are different.		
Reactive Power Capabilities	+/-0.95 pf @ generator terminals, available @ 20% of rated power Senegal: Additional requirements on reactive power capabilities outside the normal operating range			+- 0.98 @ ? available @ 20% of rated power		+- 0.95 @ ? available @ 20% of rated power

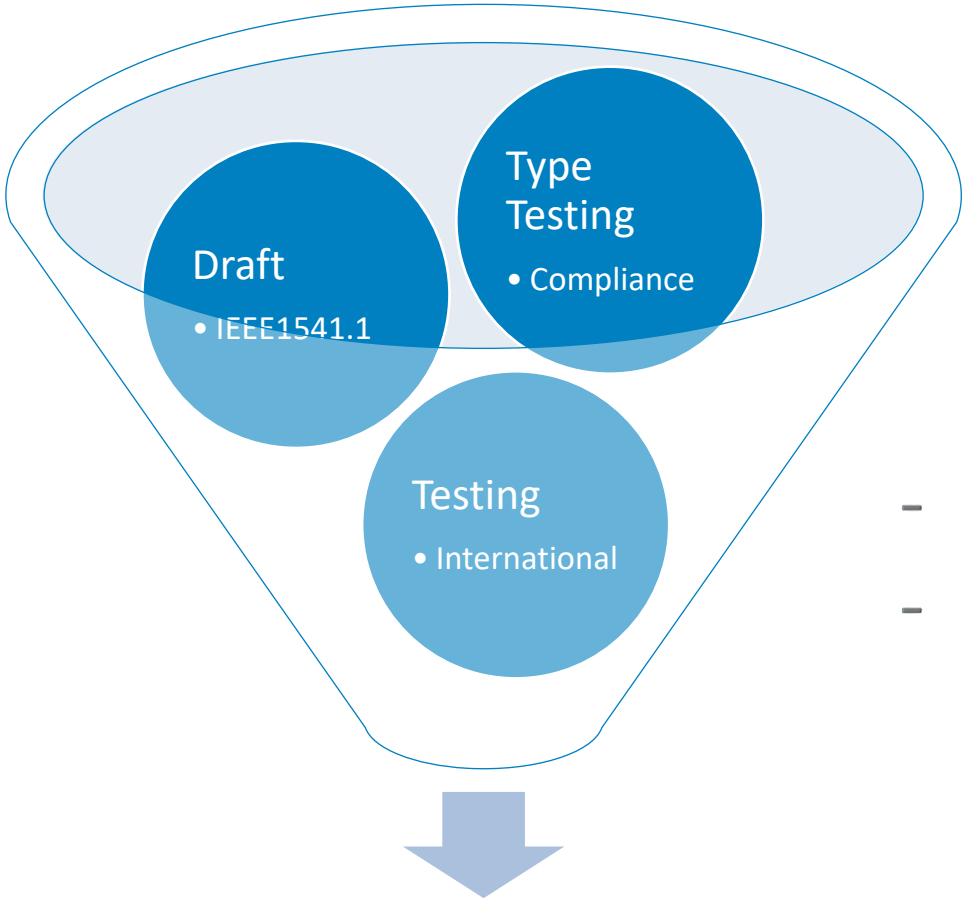
Colour coding:

	Exceeds the country requirements
	Exactly matches the country requirements
	Only partially fulfills the country requirements
	Does not fulfill the country requirements

Proposed Interim Specifications

Country	Interim/Current Requirement	Long-term Objective
Eswatini & Lesotho	NRS 097-2-1 (2024/2026)	Transition to national certification based on EG Interconnection Specifications in the medium-term.
Uganda, Kenya, Mozambique, Namibia, Zimbabwe, Senegal	NRS 097-2-1 (2017, Ed. 2.1) OR VDE-AR-N 4105 (2024)	Transition to national certification based on EG Interconnection Specifications in the short-term.
Liberia & Madagascar	VDE-AR-N 4105 (2024) (Primary) OR NRS 097-2-1	Transition to national certification based on EG Interconnection Specifications in the very short-term or periodic adoption of evolved international standards.

Type-testing



Compliant device

Interface requirements

- No testing facilities in SA/Africa
- Rely on international accredited test houses

Compliant Inverters: Approved Inverter list

CITY OF CAPE TOWN
ISIXEKO SASEKAPA
STAD KAAPSTAD

ENERGY DIRECTORATE

TYPE TESTED INVERTERS/EQUIPMENT IN TERMS OF NRS 097-2-1 2026/06/10

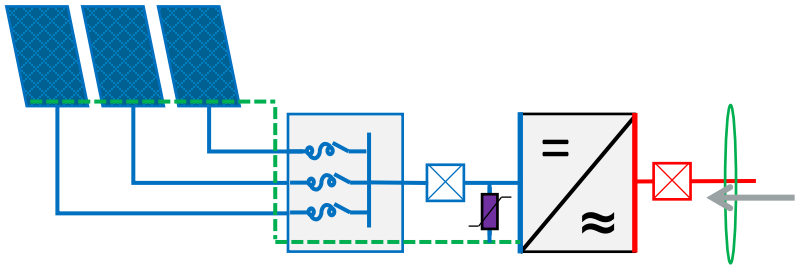
Make	Make (as on e-Services SSEG Appl Form)	Model	Inverter / Equipment type	Test House	Certificate date	Certificate valid until	Report number	Certificate Compliance number	NRS 097-2-1			Comments
									2017 Ed. 2	2017 Ed. 2.1	2024 Ed. 3	
ABB	ABB	PVS - 50 - TL	Grid-tied PV inverter	TÜV Rheinland	2020/01/22		28 111 830 029	AK 60146346 0001	Yes			Inverter may only be used in plants according to Category A3: 100 kVA - 1MVA and connection to the grid via an external customer MV/LV AC transformer.
ABB	ABB	PVS - 50 - TL - S	Grid-tied PV inverter	TÜV Rheinland	2020/01/22		28 111 830 029	AK 60146346 0001	Yes			Inverter may only be used in plants according to Category A3: 100 kVA - 1MVA and connection to the grid via an external customer MV/LV AC transformer.
ABB	ABB	PVS - 50 - TL - SX	Grid-tied PV inverter	TÜV Rheinland	2020/01/22		28 111 830 029	AK 60146346 0001	Yes			Inverter may only be used in plants according to Category A3: 100 kVA - 1MVA and connection to the grid via an external customer MV/LV AC transformer.
ABB	ABB	PVS - 50 - TL - SX2	Grid-tied PV inverter	TÜV Rheinland	2020/01/22		28 111 830 029	AK 60146346 0001	Yes			Inverter may only be used in plants according to Category A3: 100 kVA - 1MVA and connection to the grid via an external customer MV/LV AC transformer.
ABB	ABB	PVS-100-TL	Grid-tied PV inverter	TÜV Rheinland	2019/11/29		28 110 923 035	AK 60144898 0001	Yes			Inverter may only be used in plants according to Category A3: 100 kVA - 1MVA and connection to the grid via an external customer MV/LV AC transformer.
ABB	ABB	REACT2-UNO-3.6-TL	Grid-tied PV inverter	TÜV Rheinland	2018/11/07		28 111 587 003	AK 60134062 0001	Yes			A maximum of three REACT2 -BATT may be used in combination with this inverter unit
ABB	ABB	REACT2-UNO-5.0-TL	Grid-tied PV inverter	TÜV Rheinland	2018/11/07		28 111 587 003	AK 60134062 0001	Yes			A maximum of three REACT2 -BATT may be used in combination with this inverter unit
ABB	ABB	TRIO-TM-50.0-400	Grid-tied PV inverter	TÜV Rheinland	2019/07/15		28 110 633 031	AK 60141064 0001	Yes			Inverter may only be used in plants according to Category A3: 100 kVA - 1MVA and connection to the grid via an external customer MV/LV AC transformer.
Afore	AFORE	AF10K-TH	Hybrid PV inverter grid-tied	Intertek	2023/05/25		230500127SHA-001	CN-PV-230262		Yes		
Afore	AFORE	AF10K-THP	Hybrid PV inverter grid-tied	Intertek	2023/05/25		230500127SHA-001	CN-PV-230262		Yes		
Afore	AFORE	AF12K-TH	Hybrid PV inverter grid-tied	Intertek	2023/05/25		230500127SHA-001	CN-PV-230262		Yes		
Afore	AFORE	AF12K-THP	Hybrid PV inverter grid-tied	Intertek	2023/05/25		230500127SHA-001	CN-PV-230262		Yes		
Afore	AFORE	AF15K-TH	Hybrid PV inverter grid-tied	Intertek	2023/05/25		230500127SHA-001	CN-PV-230262		Yes		
Afore	AFORE	AF17K-TH	Hybrid PV inverter grid-tied	Intertek	2023/05/25		230500127SHA-001	CN-PV-230262		Yes		
Afore	AFORE	AF20K-TH	Hybrid PV inverter grid-tied	Intertek	2023/05/25		230500127SHA-001	CN-PV-230262		Yes		
Afore	AFORE	AF25K-TH	Hybrid PV inverter grid-tied	Intertek	2023/05/25		230500127SHA-001	CN-PV-230262		Yes		
Afore	AFORE	AF3.6K-SL	Hybrid PV inverter grid-tied	Dekra	2021/03/10		6098057.50	6098057.01AOC		Yes		
Afore	AFORE	AF30K-TH	Hybrid PV inverter grid-tied	Intertek	2023/05/25		230500127SHA-001	CN-PV-230262		Yes		
Afore	AFORE	AF3K-SL	Hybrid PV inverter grid-tied	Dekra	2021/03/10		6098057.50	6098057.01AOC		Yes		
Afore	AFORE	AF3K-TH	Hybrid PV inverter grid-tied	Intertek	2023/05/25		230500127SHA-001	CN-PV-230262		Yes		
Afore	AFORE	AF3K-THP	Hybrid PV inverter grid-tied	Intertek	2023/05/25		230500127SHA-001	CN-PV-230262		Yes		
Afore	AFORE	AF4.6K-SL	Hybrid PV inverter grid-tied	Dekra	2021/03/10		6098057.50	6098057.01AOC		Yes		
Afore	AFORE	AF4K-SL	Hybrid PV inverter grid-tied	Dekra	2021/03/10		6098057.50	6098057.01AOC		Yes		

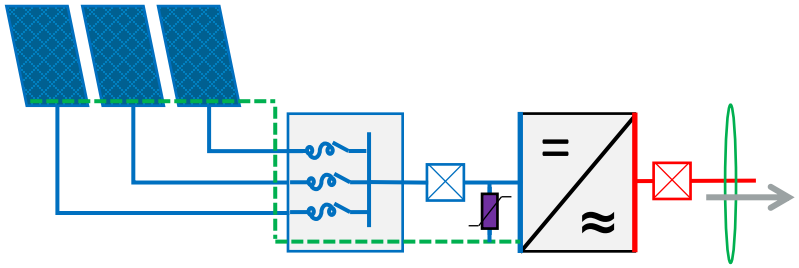
Source: City of Cape Town Approved inverter list (https://resource.capetown.gov.za/documentcentre/Documents/Forms,%20notices,%20tariffs%20and%20lists/Approved%20Photovoltaic%20(PV)%20Inverter%20List.pdf)

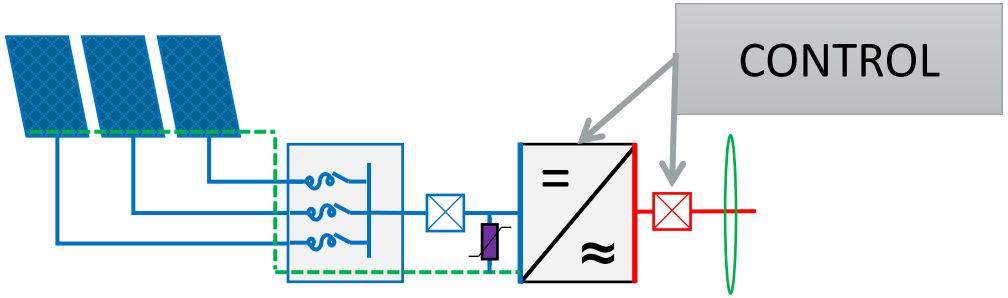
Interconnection specifications: Key aspects to cover

- Interface requirements
- Requirements for the Utility
- Requirements for the Generator (devices and units)

Utility Compatibility







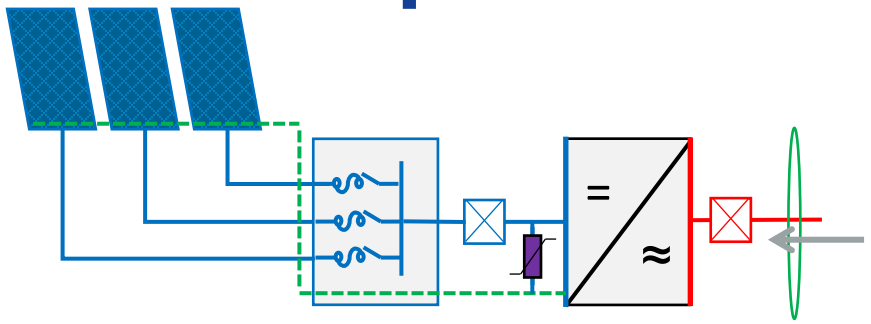
Summarise as:

1) What to expect?

2) What is allowed?

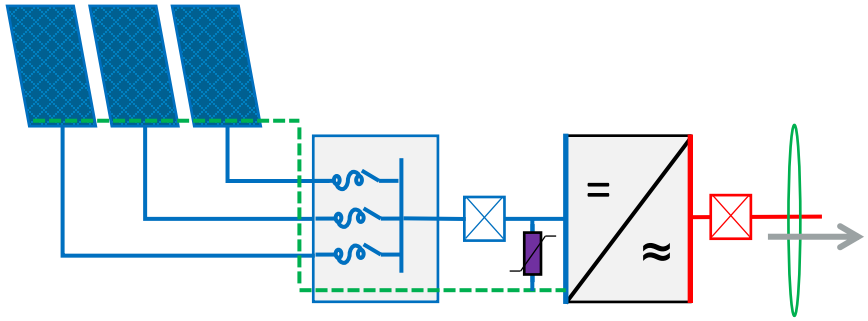
3) What to do?

What to Expect?



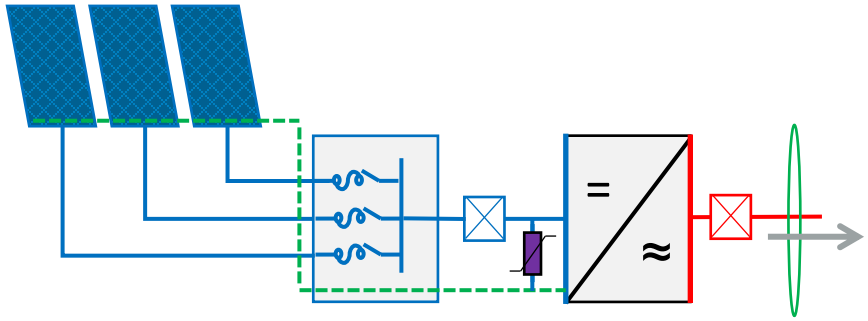
- Voltage, current and frequency
- EMC
- Power Quality
- Fault level

What Allowed?



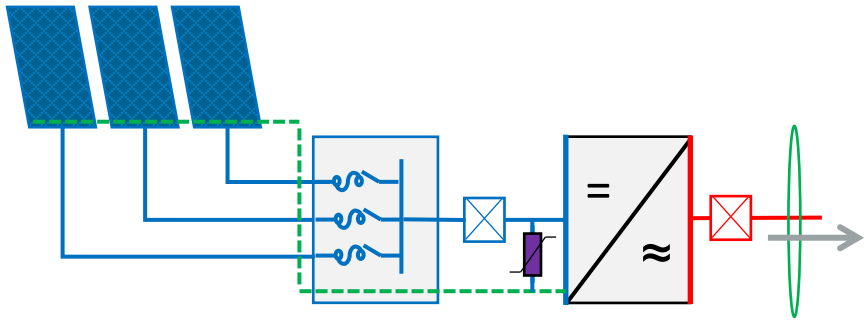
- Inject current - not voltage
  - Voltage control (future requirements) may lead to instability
- Synchronise
- Operate within trip limits
  - DC current and residual DC current
  - Voltage and frequency
- No islanding
  - Out of phase reclosing

What Allowed?



- PQ contributions
  - Flicker
  - Voltage unbalance
  - Harmonics and waveform distortion
  - DC injection

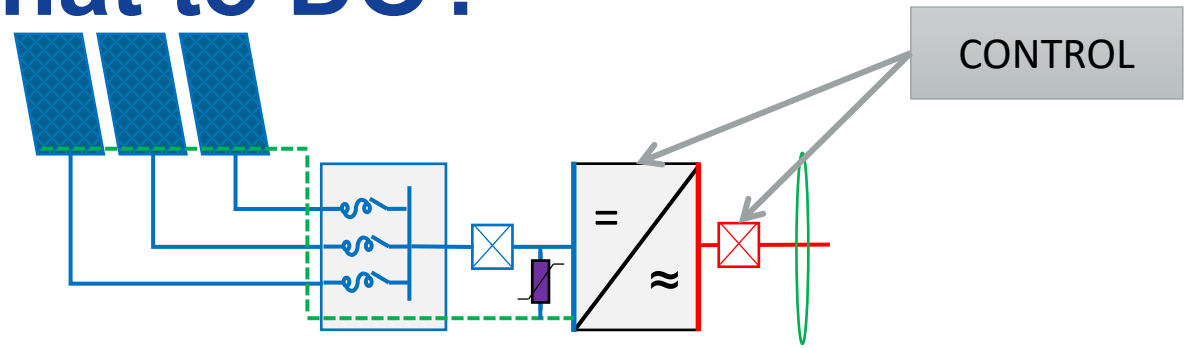
What Allowed?



Applies at the generator terminals!

- Power factor
- Typical values (South Africa based on international):
  - Up to 100 kW pf > 0.98
  - Between 100 kW and 1 MW pf > 0.95
- EMC / Mains signalling

What to DO?



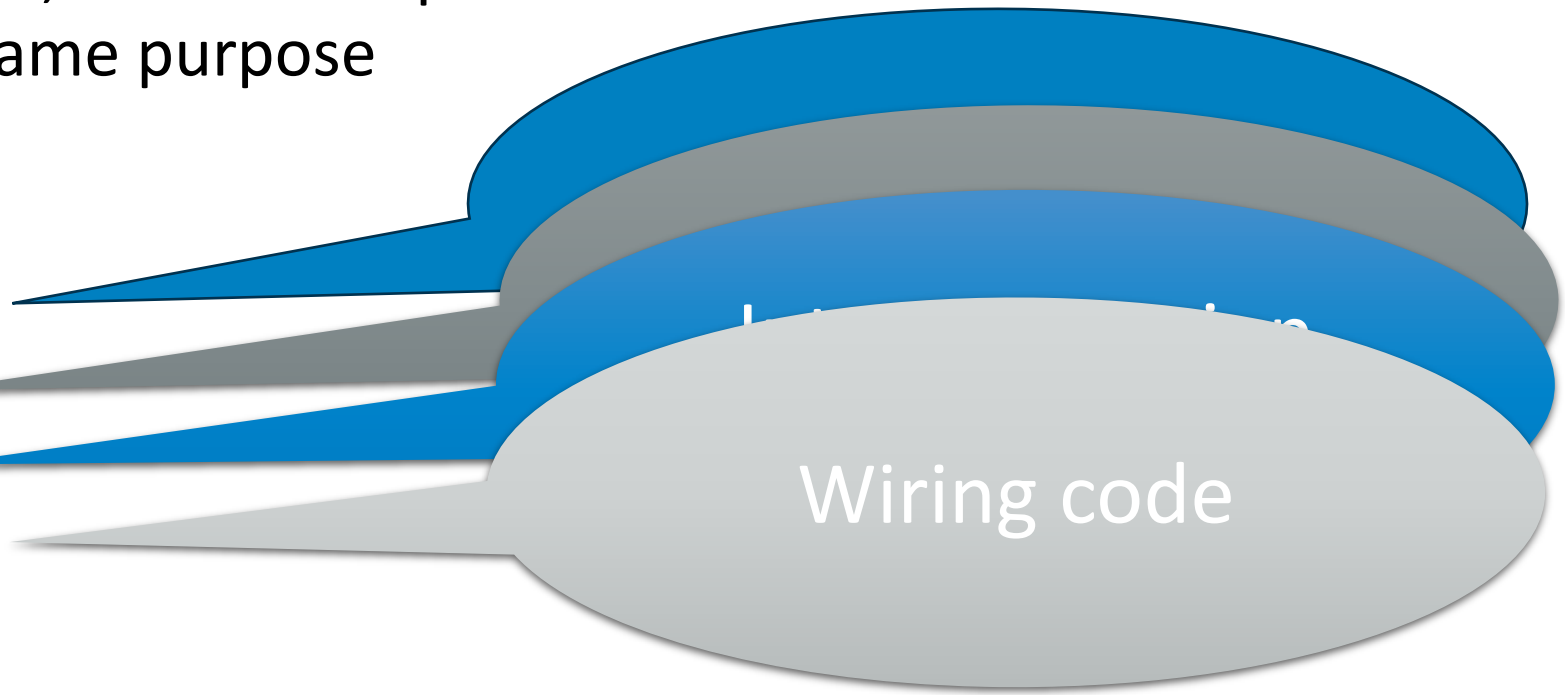
- **Safety disconnect unit**

- Ensure disconnection
  - Including Anti-islanding
- Redundancy

- Non-inverter – relays VDE 0126-1-1 certified

Summary of Technical Specifications

- Several standards, codes and specifications
  - All have the same purpose



- Equipment
- Network
- Interface
- Installation

- Align and work together for a safe sustainable power system

SIMPLIFIED CONNECTION CRITERIA

Grid Impact Studies

Grid Code Requirement

- Evaluate impact of generation on the network
- The utility is responsible for the network:
  - Regulatory compliance
  - Power quality
  - Impacts on other customers
  - Impacts on safety of people and equipment

Grid Code Requirement

- Achieved by: Grid / Network / System Impact Study
- Major planning resources
- For small units, disproportionate effort

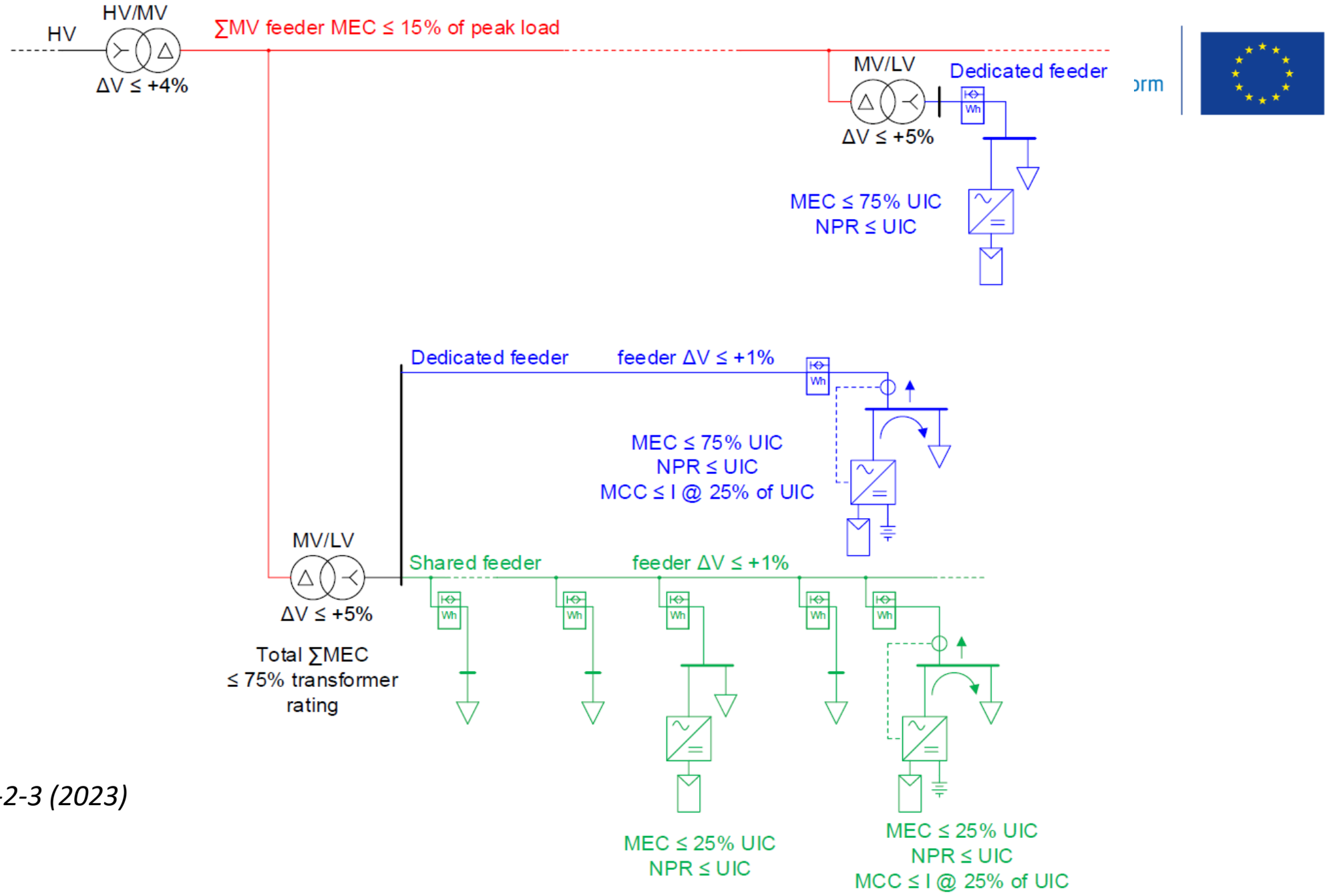
➢ Simplified Connection Criteria

Simplified Connection Criteria

- Simplified “Studies”
  - Per DG request
    - LV network
  - Smaller systems only
  - Low penetration levels

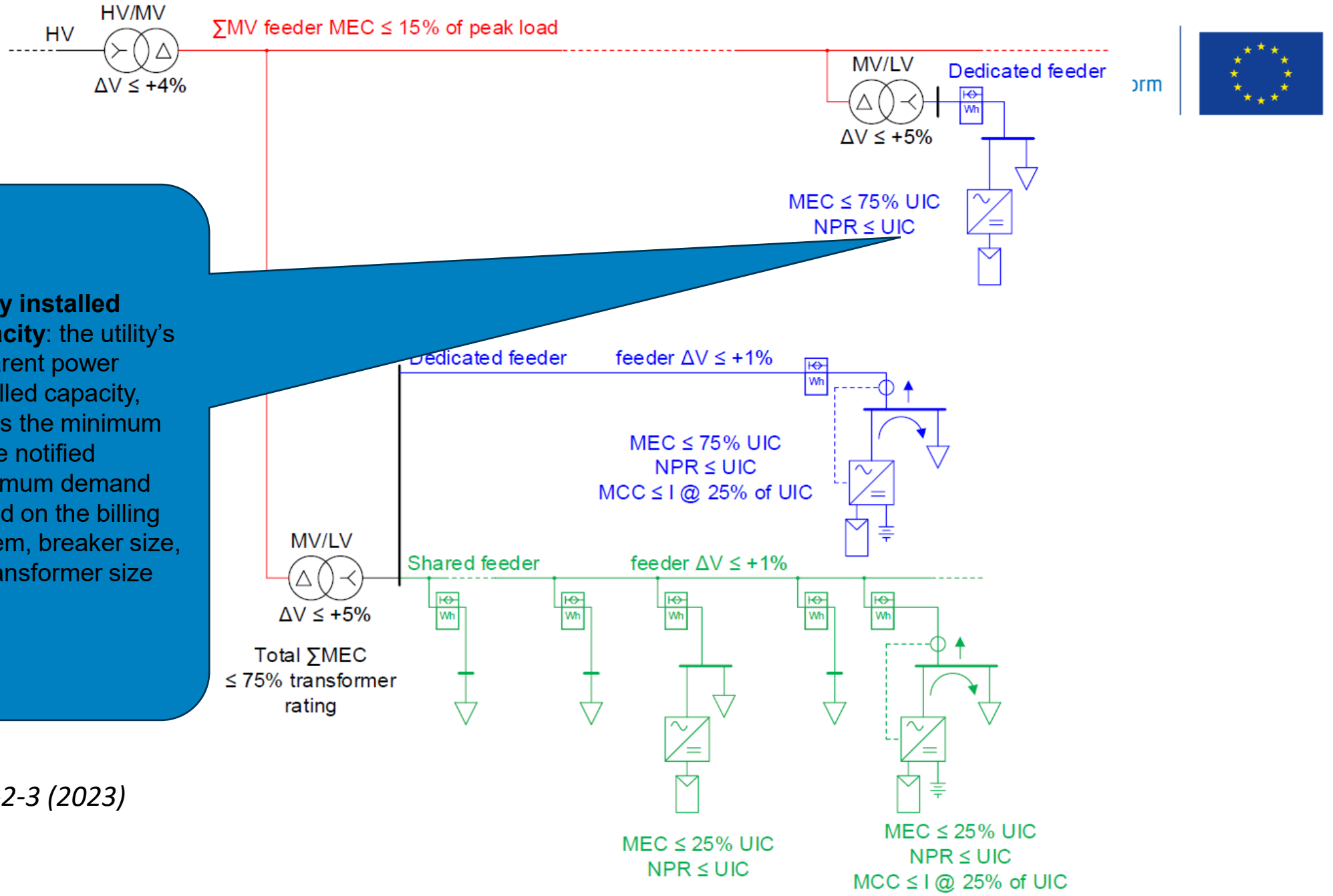
Simplified Connection Criteria

- Simplified Grid or Network Impact “Studies” mainly covers the DG Capacity and Maximum Export to the grid relative to
    - The supply point (NMD) capacity
    - Considering shared or dedicated feeder customers
    - The Feeder Capacity (Dedicated Feeder)
    - MV/LV Transformer capacity
    - MV Feeder Peak Load
    - HV/LV Transformer capacity



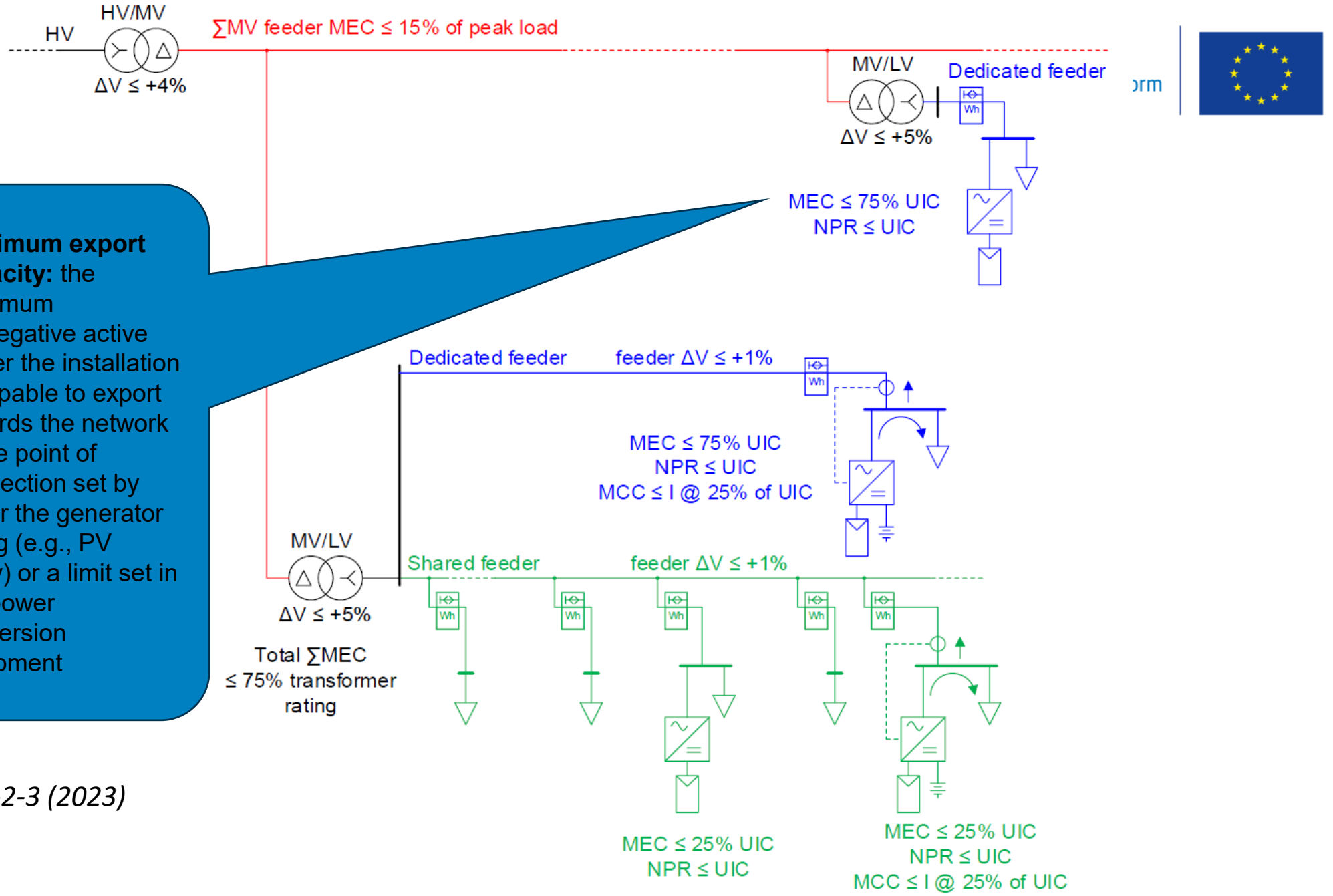
Source: NRS 097-2-3 (2023)

utility installed capacity: the utility's apparent power installed capacity, that is the minimum of the notified maximum demand stated on the billing system, breaker size, or transformer size

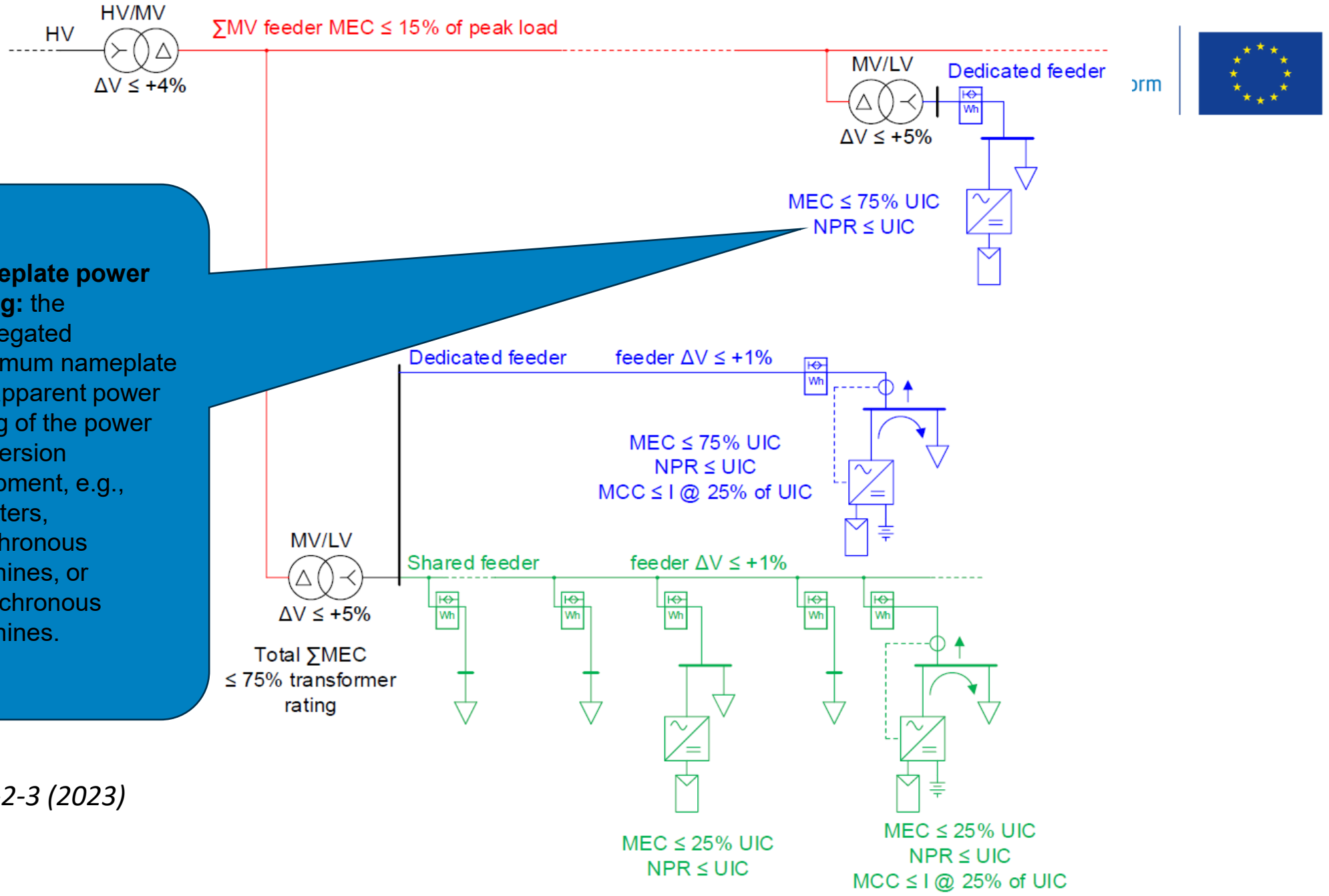


Source: NRS 097-2-3 (2023)

maximum export capacity: the maximum aggregative active power the installation is capable to export towards the network at the point of connection set by either the generator rating (e.g., PV array) or a limit set in the power conversion equipment

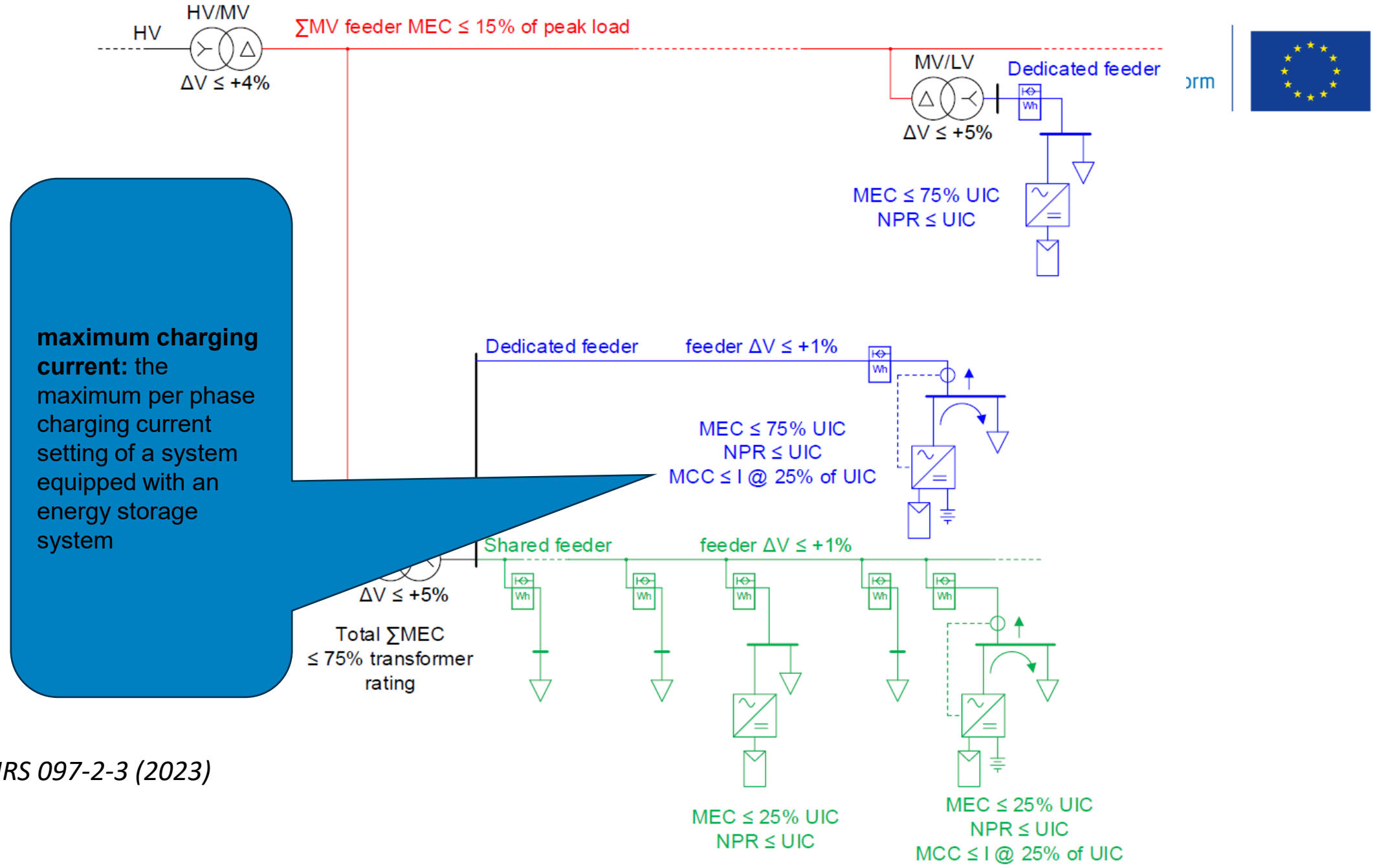


Source: NRS 097-2-3 (2023)



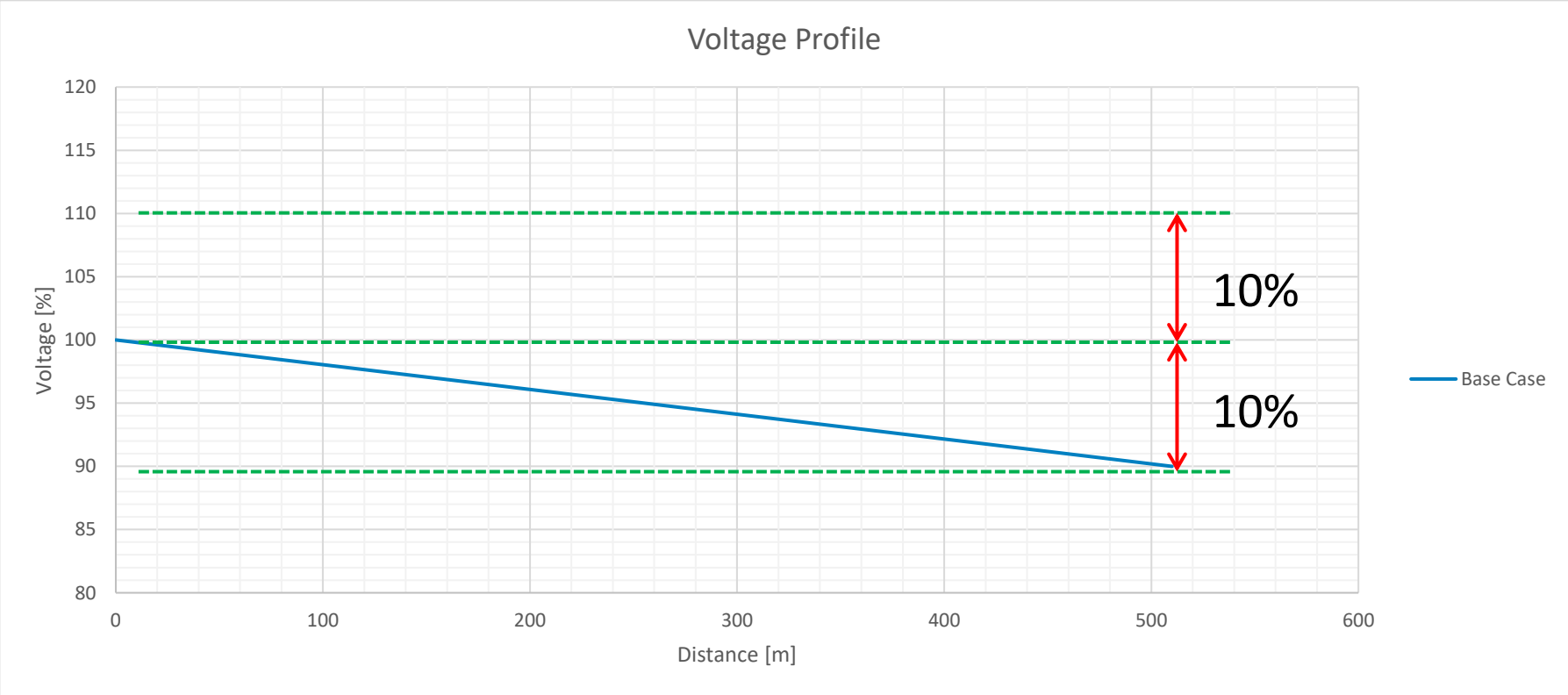
nameplate power rating: the aggregated maximum nameplate AC apparent power rating of the power conversion equipment, e.g., inverters, synchronous machines, or asynchronous machines.

Source: NRS 097-2-3 (2023)

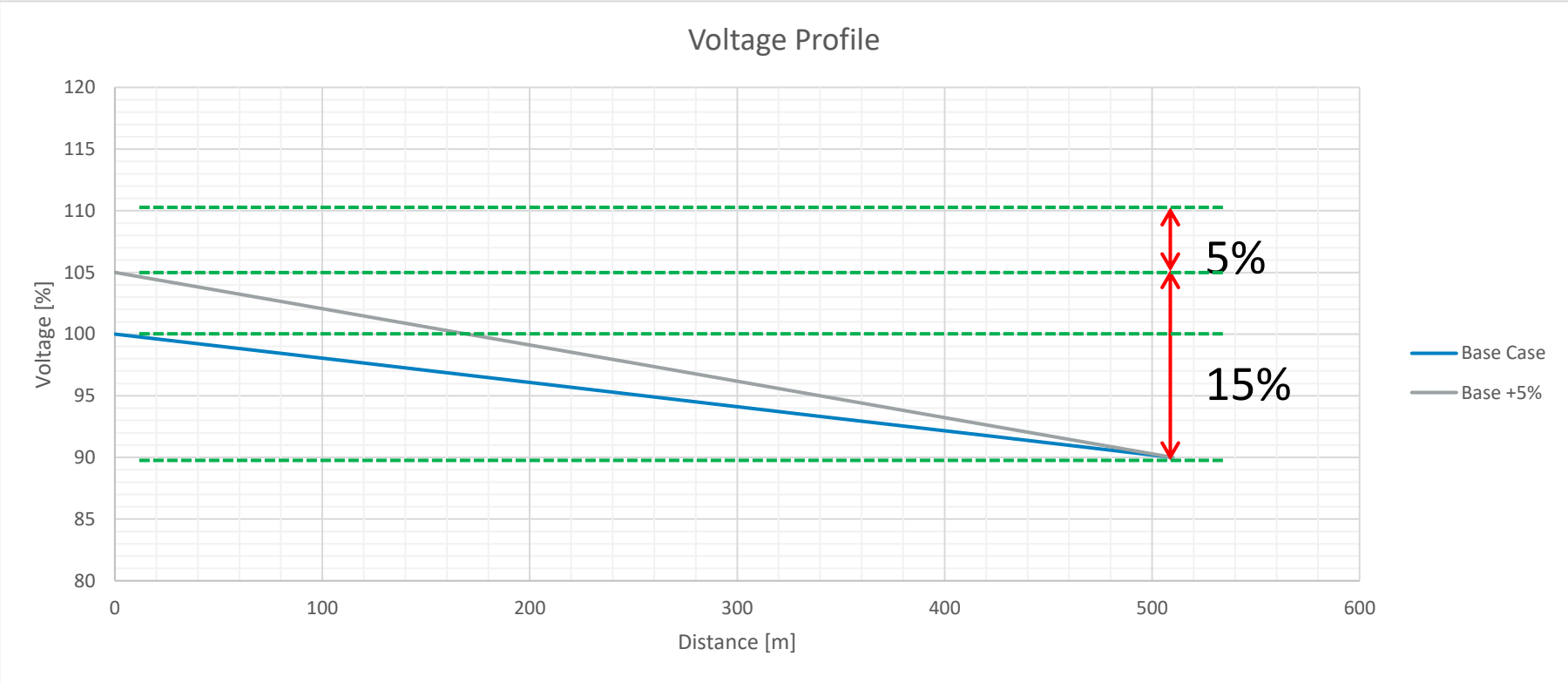


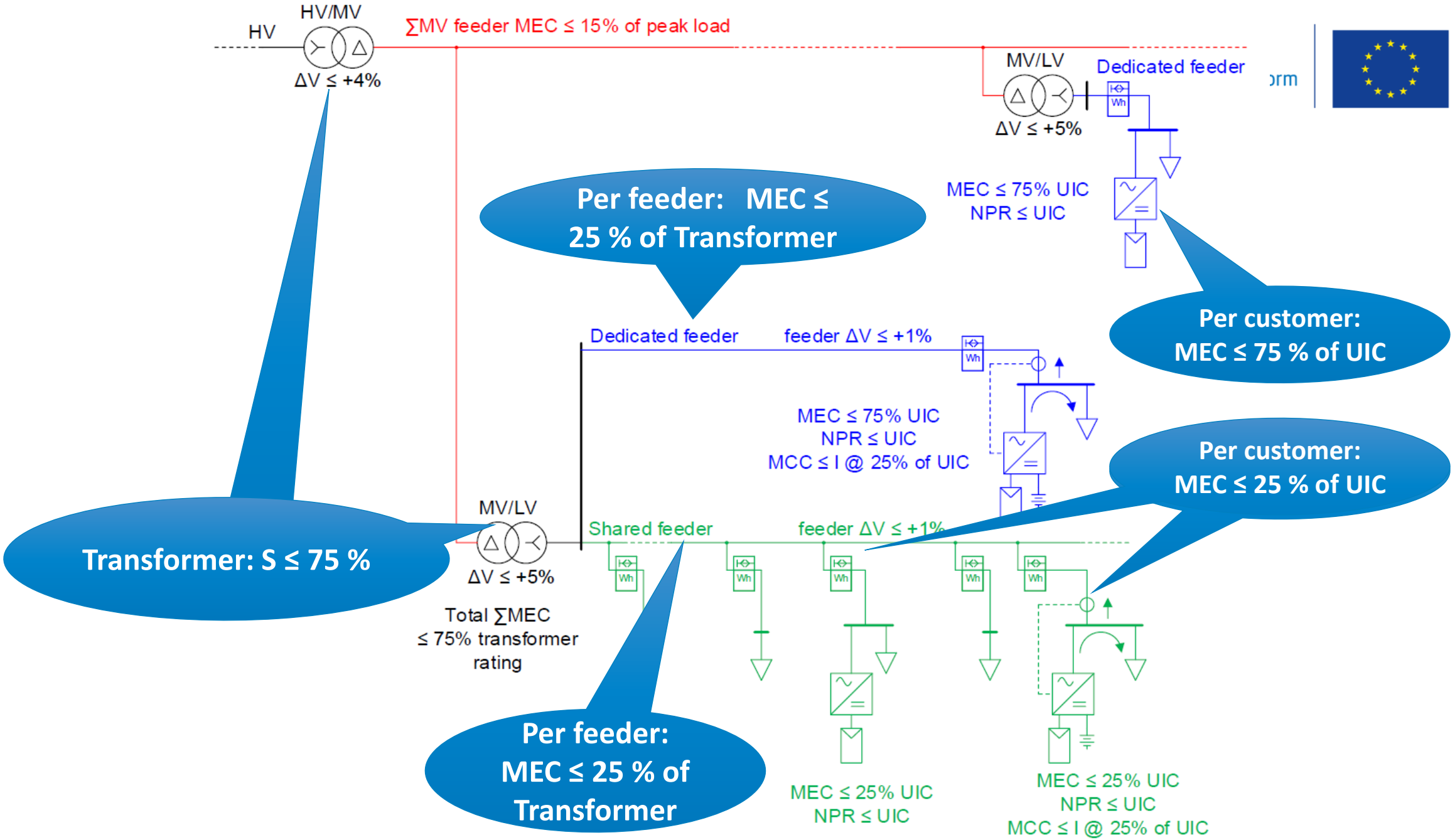
Source: NRS 097-2-3 (2023)

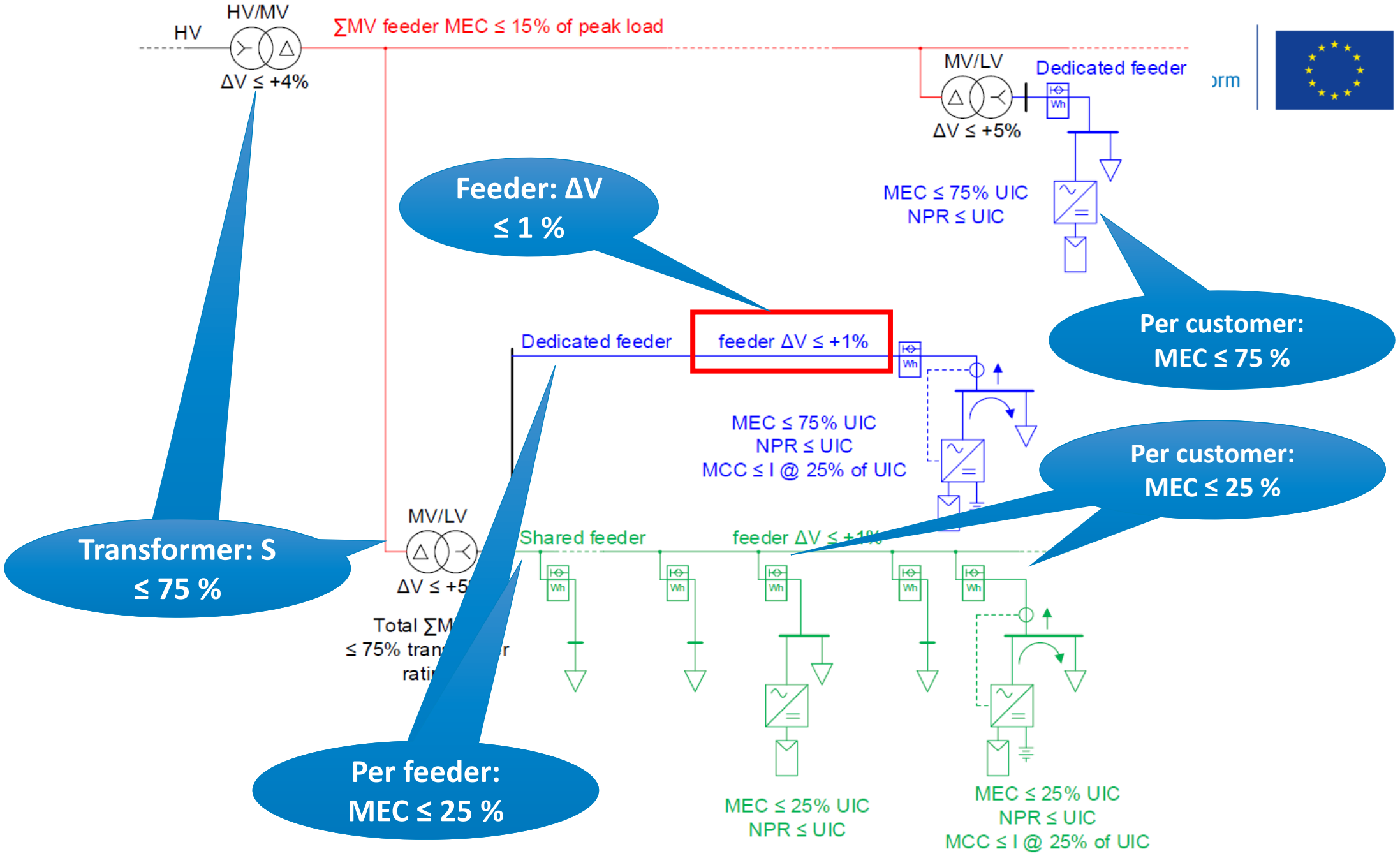
Voltage


Voltage Profile
120
115
110
105
100
95
90
85
80
Voltage [%]
0
100
200
300
400
500
600
Distance [m]
10%
10%
Base Case

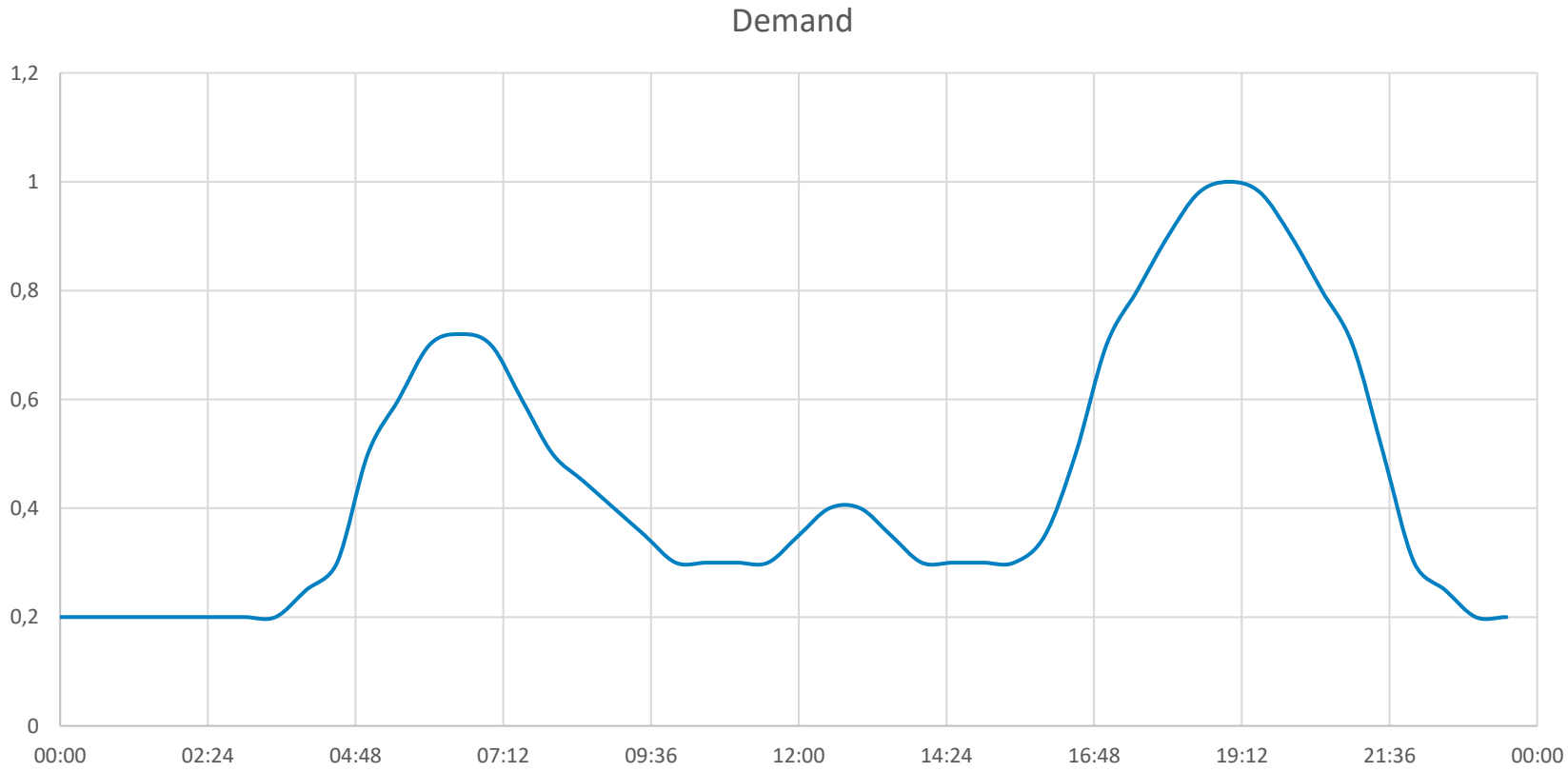
Voltage

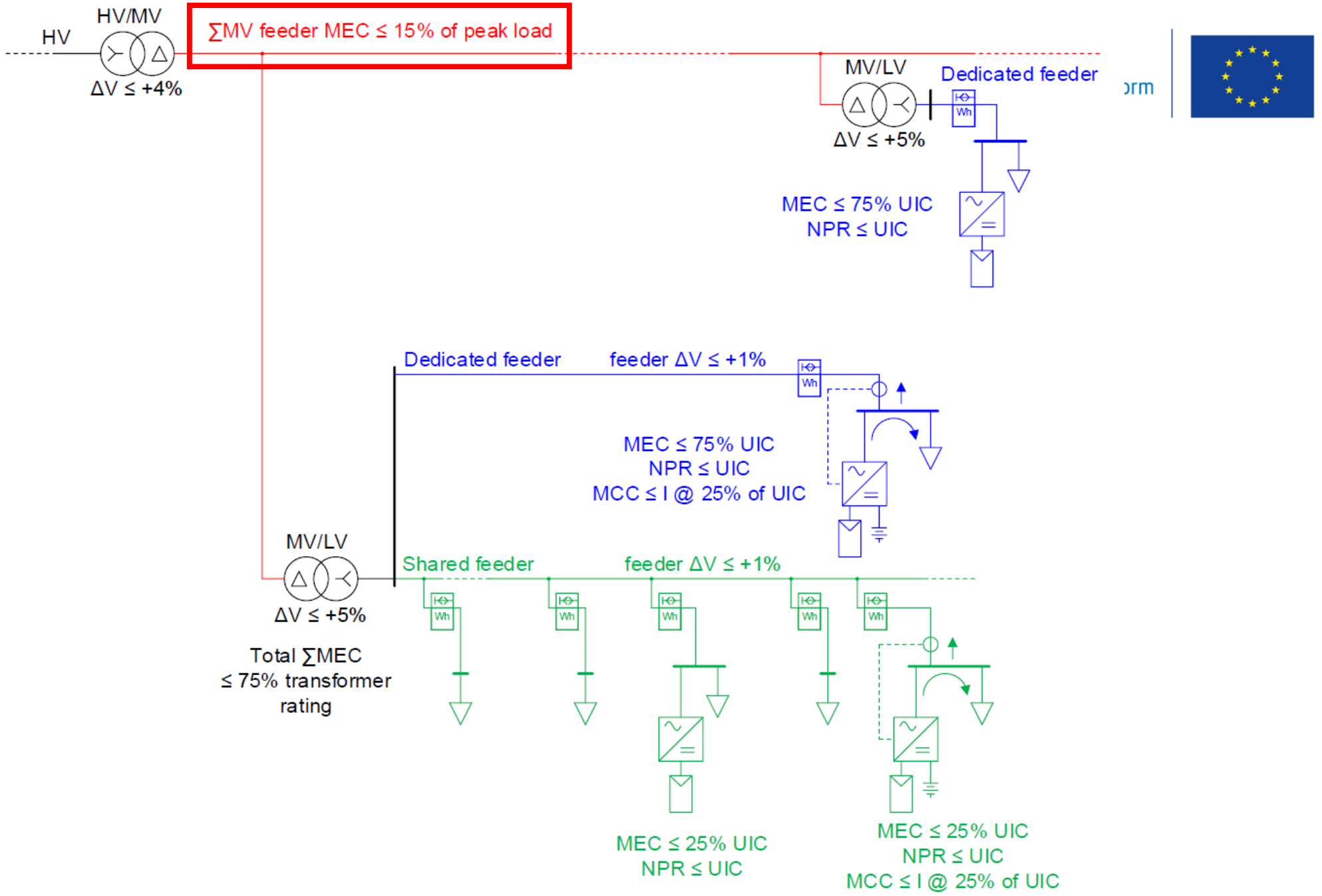

Voltage Profile
120
115
110
105
100
95
90
85
80
Voltage [%]
0
100
200
300
400
500
600
Distance [m]
5%
15%
Base Case
Base +5%


HV
HV/MV
ΔV ≤ +4%
∑MV feeder MEC ≤ 15% of peak load
MV/LV
ΔV ≤ +5%
Dedicated feeder
MEC ≤ 75% UIC
NPR ≤ UIC
Per feeder: MEC ≤ 25 % of Transformer
Per customer: MEC ≤ 75 % of UIC
Dedicated feeder
feeder ΔV ≤ +1%
MEC ≤ 75% UIC
NPR ≤ UIC
MCC ≤ I @ 25% of UIC
Per customer: MEC ≤ 25 % of UIC
Transformer: S ≤ 75 %
MV/LV
ΔV ≤ +5%
Shared feeder
feeder ΔV ≤ +1%
Total ∑MEC ≤ 75% transformer rating
Per feeder: MEC ≤ 25 % of Transformer
MEC ≤ 25% UIC
NPR ≤ UIC
MEC ≤ 25% UIC
NPR ≤ UIC
MCC ≤ I @ 25% of UIC


HV
HV/MV
ΔV ≤ +4%
∑MV feeder MEC ≤ 15% of peak load
MV/LV
ΔV ≤ +5%
Dedicated feeder
MEC ≤ 75% UIC
NPR ≤ UIC
Feeder: ΔV ≤ 1 %
Per customer: MEC ≤ 75 %
Dedicated feeder
feeder ΔV ≤ +1%
MEC ≤ 75% UIC
NPR ≤ UIC
MCC ≤ I @ 25% of UIC
Per customer: MEC ≤ 25 %
Transformer: S ≤ 75 %
MV/LV
ΔV ≤ +5
Shared feeder
feeder ΔV ≤ +1%
Per feeder: MEC ≤ 25 %
MEC ≤ 25% UIC
NPR ≤ UIC
MEC ≤ 25% UIC
NPR ≤ UIC
MCC ≤ I @ 25% of UIC

Typical Daily Profile




HV
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ΔV ≤ +4%
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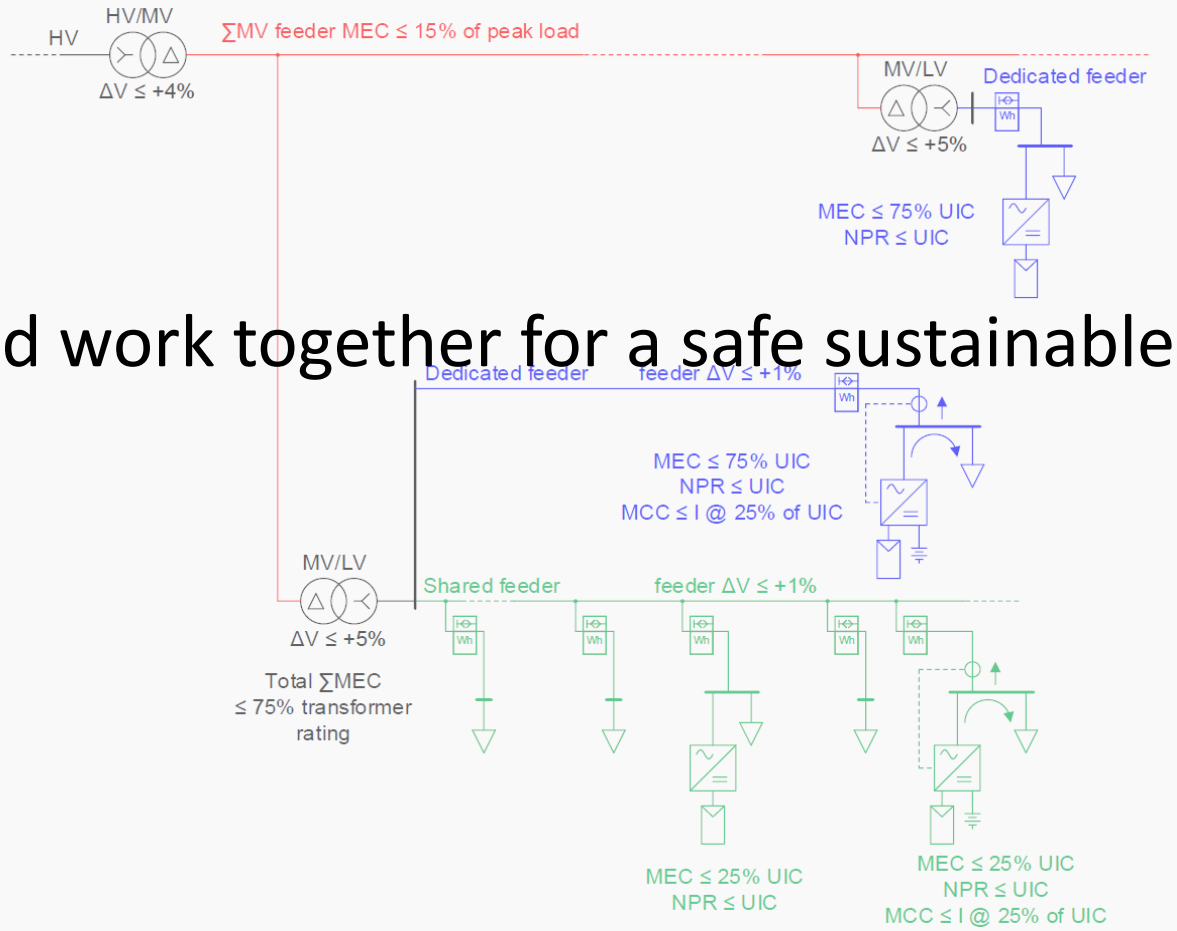
MV/LV
Dedicated feeder
ΔV ≤ +5%
MEC ≤ 75% UIC
NPR ≤ UIC
Dedicated feeder
feeder ΔV ≤ +1%
MEC ≤ 75% UIC
NPR ≤ UIC
MCC ≤ I @ 25% of UIC
MV/LV
ΔV ≤ +5%
Shared feeder
feeder ΔV ≤ +1%
Total ∑MEC
≤ 75% transformer
rating
MEC ≤ 25% UIC
NPR ≤ UIC
MEC ≤ 25% UIC
NPR ≤ UIC
MCC ≤ I @ 25% of UIC

Simplified Connection Criteria

- DG kW <= NMD / circuit breaker capacity
- DG max export kW <= 25% of NMD / circuit breaker capacity
- If max export > 4.6kVA, is it balanced across phases?
- Feeder cable max voltage rise <=1%
- Total DG max export on ALL LV feeders <75% of MV/LV transformer rating?
- Total DG max export on MV feeder <15% of MV feeder peak load?

Summary of Simplified Connection Criteria



- Align and work together for a safe sustainable power system

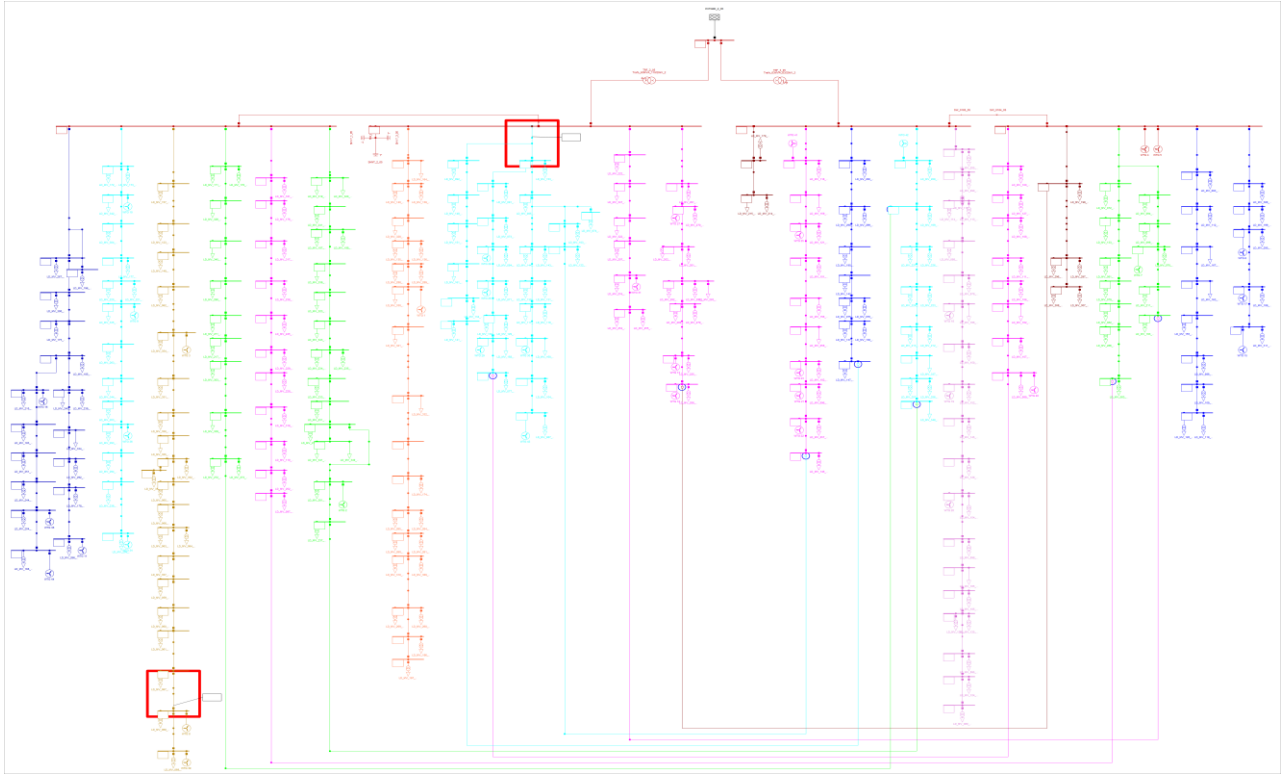
OPTIONAL

Hosting Capacity

Hosting Capacity

- Grid or Network level

- UPFRONT
  - Support simplified criteria

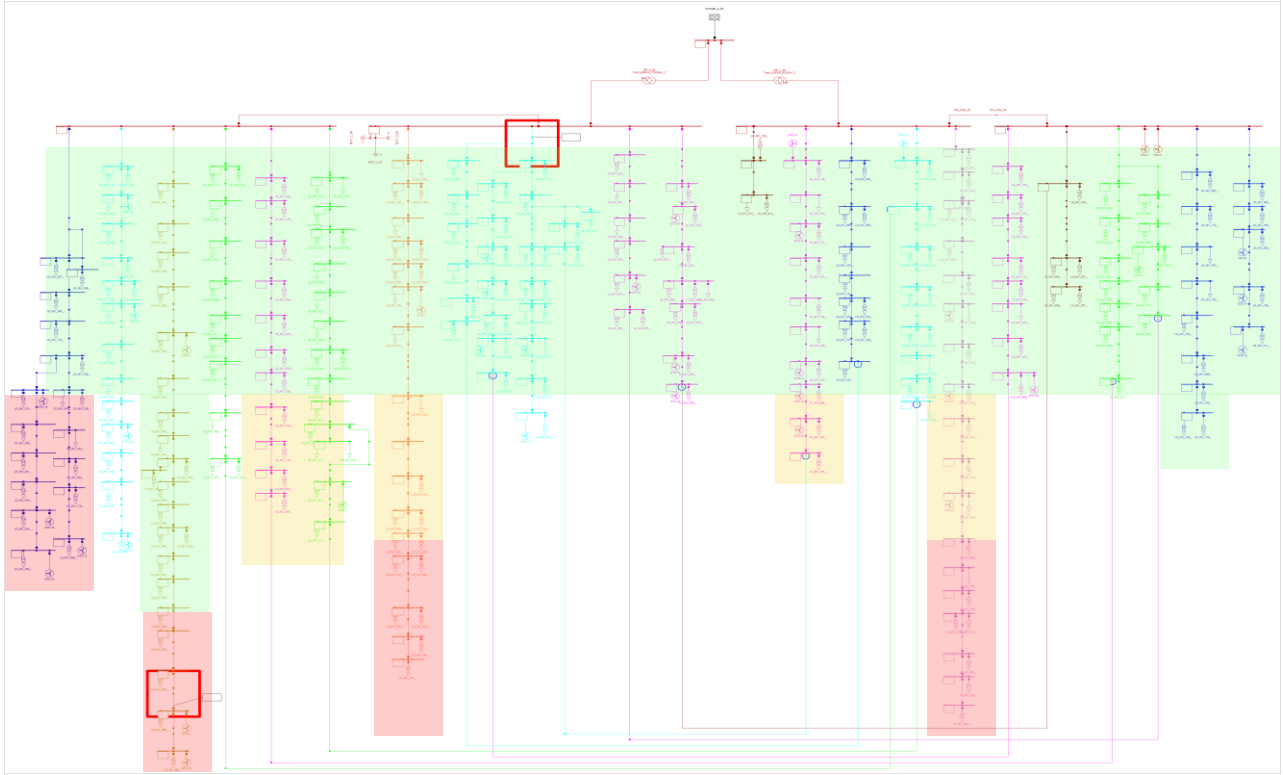


Hosting Capacity

1) Grid or Network level

2) UPFRONT

- Maximum capacity for grid
  - And per network
- Where no problems
- Where may be problems
- Where will be problems



Summary

- Technical requirements
  - Grid codes
  - Wiring codes
  - Interconnection specifications
- Grid impact
  - Grid / Network / System impact studies
  - Simplified Connection Criteria
  - Hosting capacity evaluation

- Align and work together for a safe sustainable power system