Considerations on modelling grid-integrated PV

Presentation at Workshop on THE GRID INTEGRATION OF RENEWABLE ENERGY: CHALLENGES AND FIELD EXPERIENCES WITH GRID COMPLIANCE ASSESSMENT

CSIR Energy Centre

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The CSIR at a glance

- The CSIR's Executive Authority is the South African Minister of Science and Technology

In numbers:

72yrs
1945 - 2017

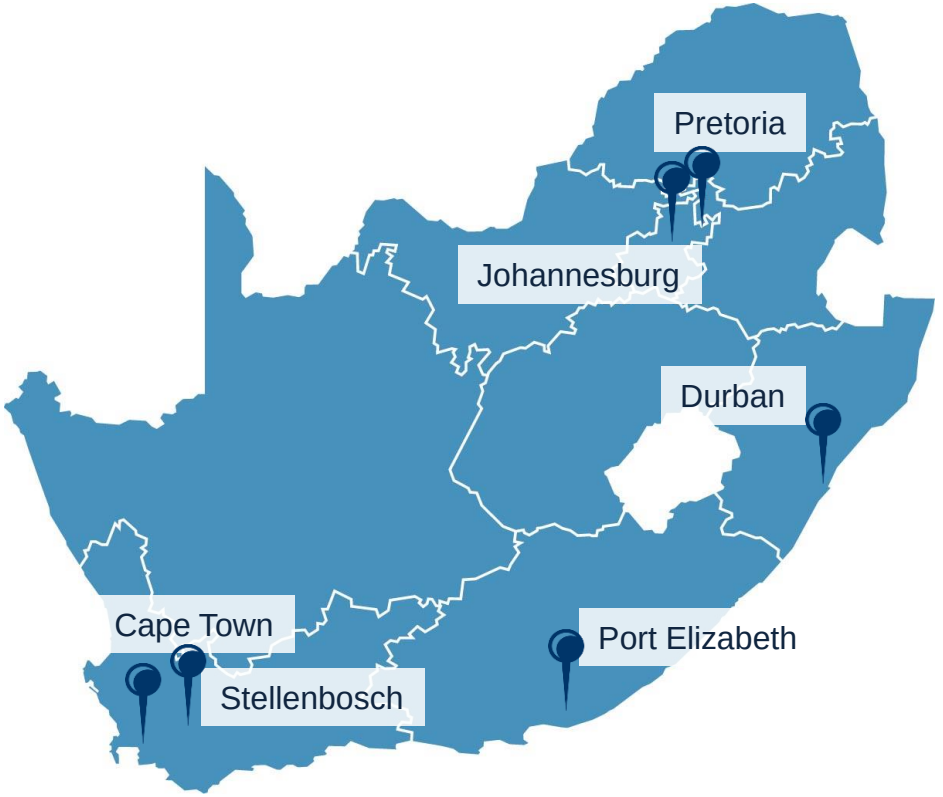
2 668
Total staff

350
SET base with PhD

490
Publication equivalents

~ $200 m
Total operating income

1 980
Total in SET base



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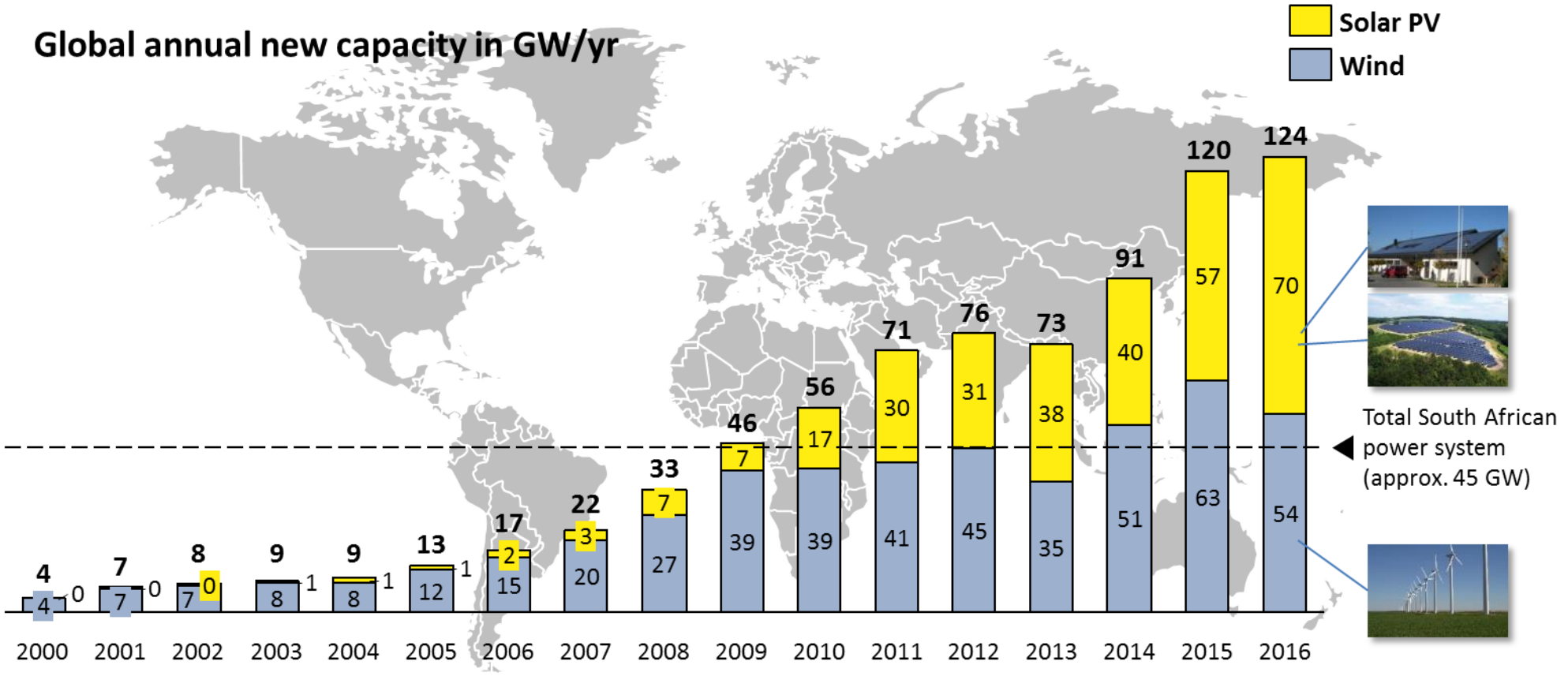
Based on 2015/16 forecast

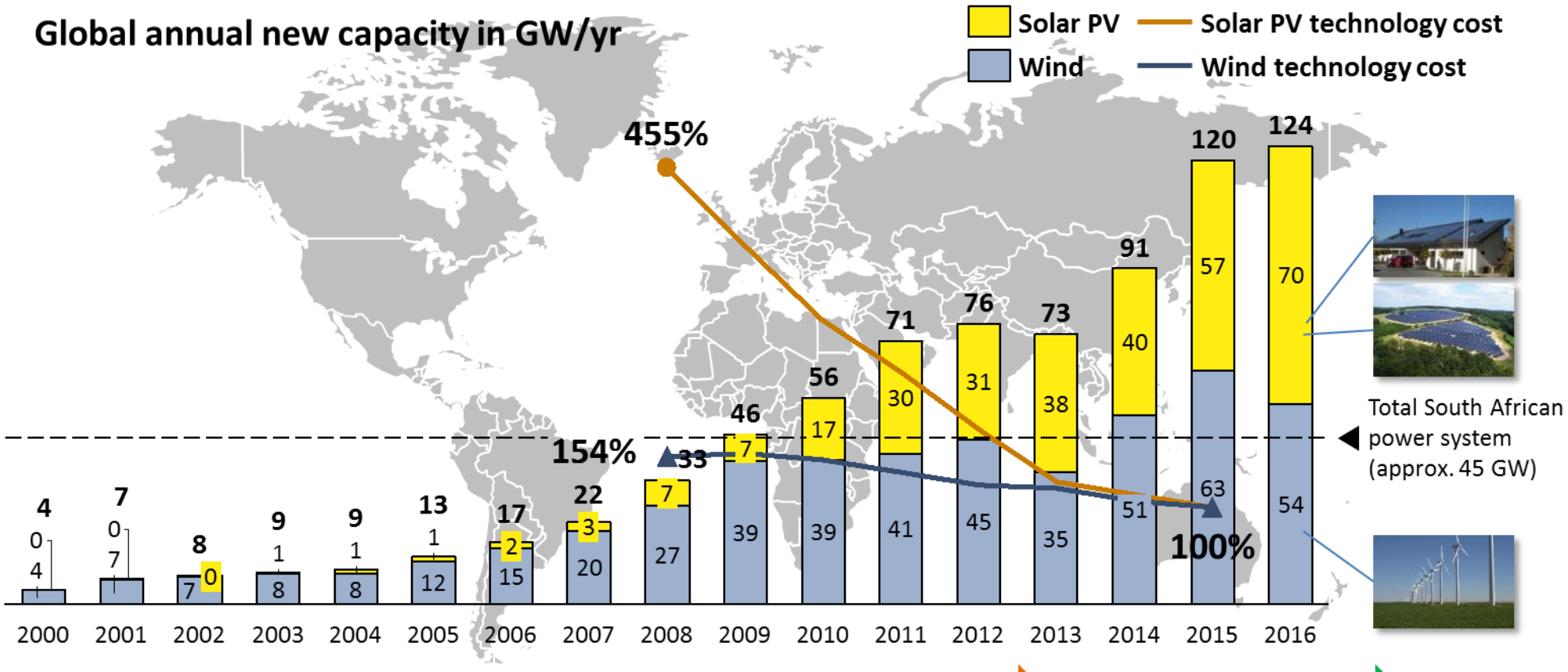
World:
In 2016, 124 GW of new wind and solar PV capacity installed globally



This is all very new: Roughly 80% of the globally existing solar PV capacity was installed during the last five years

Sources: GWEC; EPIA; BNEF; CSIR analysis

World:
Significant cost reductions materialised in the last 5-8 years



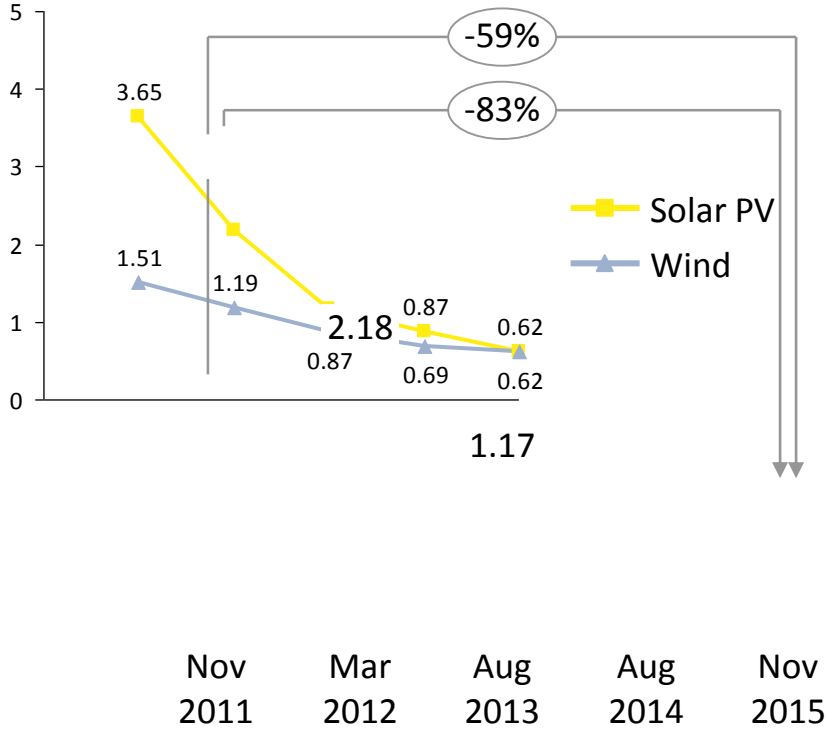
Sources: IEA; GWEC; EPIA; BNEF; CSIR analysis

Actual tariffs: new wind/solar PV 40% cheaper than new coal in RSA

Results of Department of Energy's RE IPP Procurement Programme (REIPPPP) and Coal IPP Proc. Programme

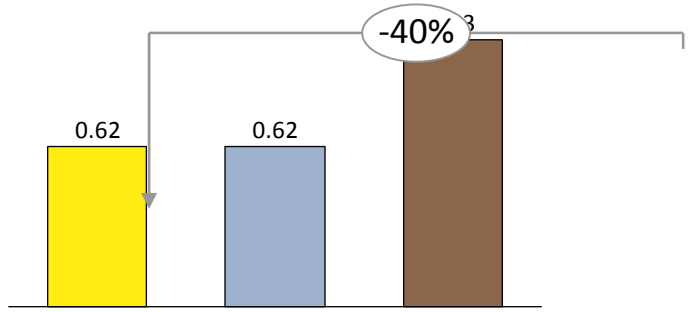
Significant reductions in actual tariffs …

Actual average tariffs in R/kWh (Apr-2016-R)



… have made new solar PV & wind power 40% cheaper than new coal in South Africa today

Actual average tariffs in R/kWh (Apr-2016-R)



Notes: Exchange rate of 14 USD/ZAR assumed Sources: http://www.energy.gov.za/files/renewable-energy-status-report/Market-Overview-and-Current-Levels-of-Renewable-Energy-Deployment-NERSA.pdf; http://www.saippa.org.za/Portals/24/Documents/2016/Coal%20IPP%20factsheet.pdf; http://www.ee.co.za/wp-content/uploads/2016/10/New_Power_Generators_RSA-CSIR-14Oct2016.pdf; StatsSA on CPI; CSIR analysis

What is different today as compared to just a few years ago?

Renewables are now cost competitive to alternative new-build options in large parts of Africa

- Renewables became cost competitive to conventionals during the last decade (PV: last 2-3 years)
- Subsidy-driven market creation in first-mover renewables regions (US, Europe, Japan) led to technology improvements and mass manufacturing

In matured markets, renewables are a substitution in a volume-wise stagnating energy system

- Renewables compete with an existing, steady-state energy system fuel savers for the existing fleet
- Major incumbents with business models based on “large, central” suffer in terms of market share

In emerging markets, this is different: renewables can be at the core of the energy-system expansion

- Renewables compete with alternative new-built options / future scenarios for the energy structure
- More than just fuel savers, they change the entire paradigm on which energy systems were traditionally planned, designed, built and operated (large, central)

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Modelling Transmission vs Distribution

Transmission

- Balanced network and load
- High X/R ratio
- Voltage control via reactive power control
- High levels of network visibility and control
- Geographic diversity
- Focus on dynamic stability
- Control of dispatchable Gx

Distribution

- Unbalanced network
- Unbalanced loads
- Low X/R ratio
- Voltage control via tap changing
- Passive network - low levels of network visibility and control
- Stochastic variation in load
- Stochastic variation in generation (PV)
- Focus on adequacy

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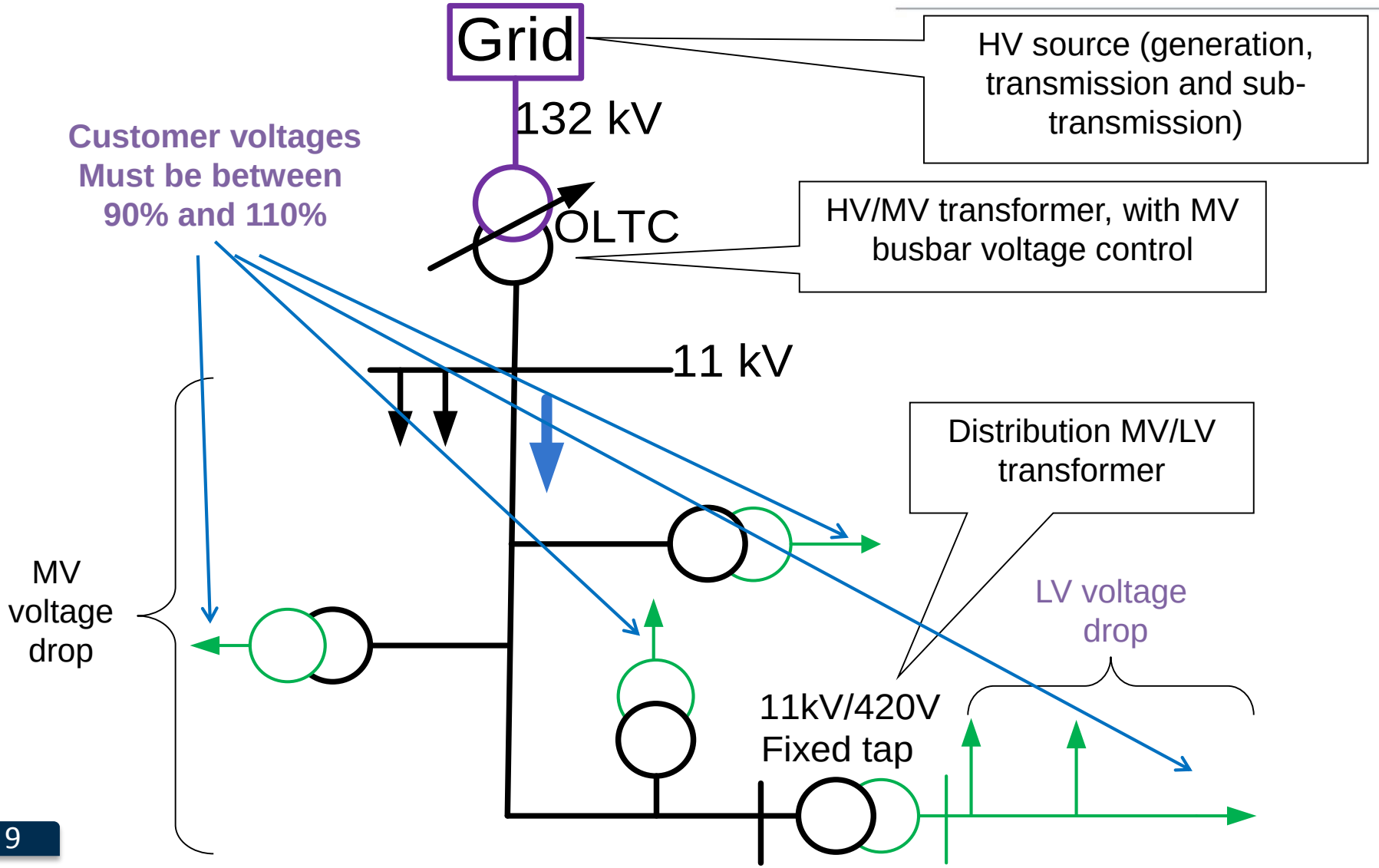
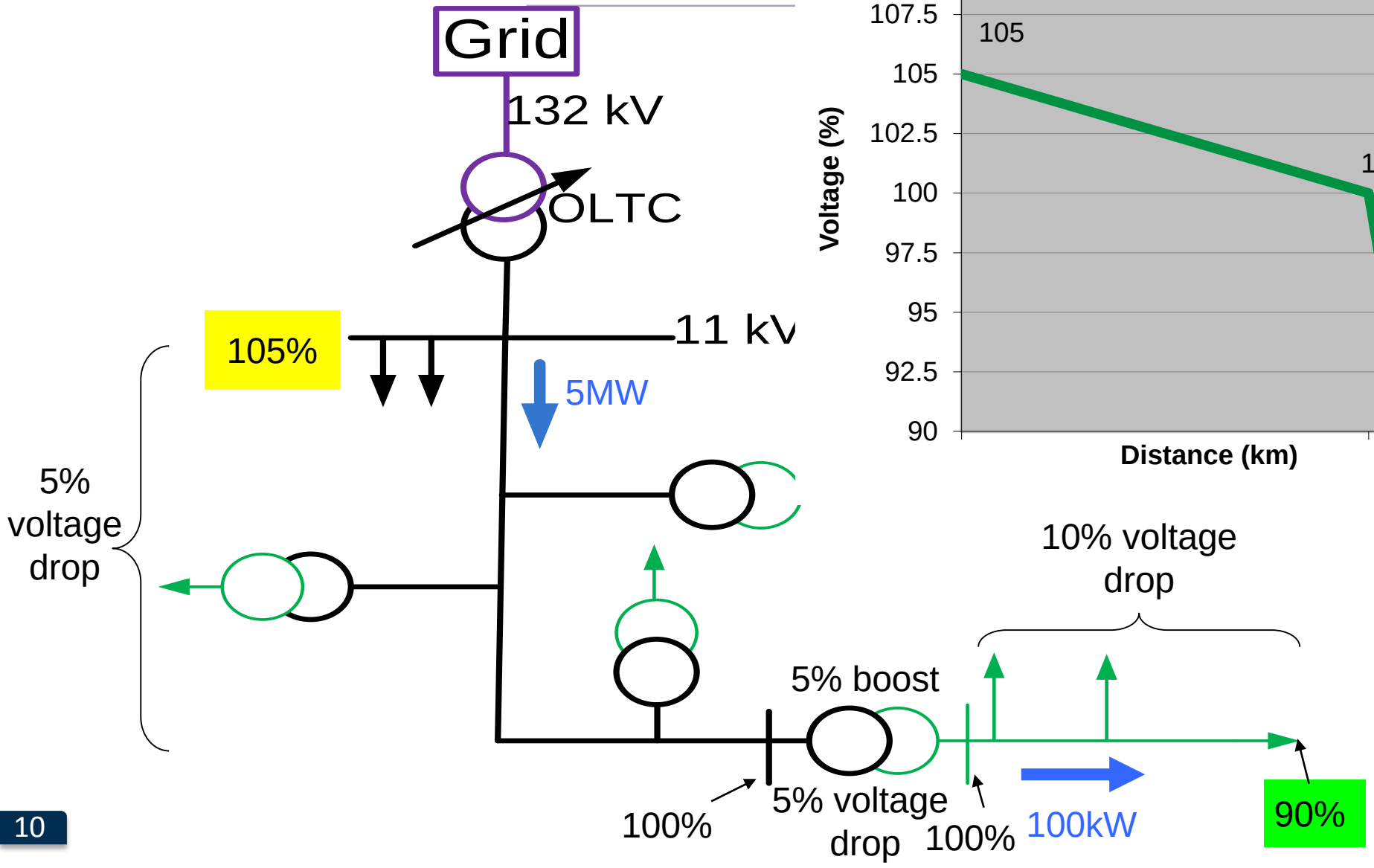
Illustration of voltage rise constraints on Distribution networks with embedded generation

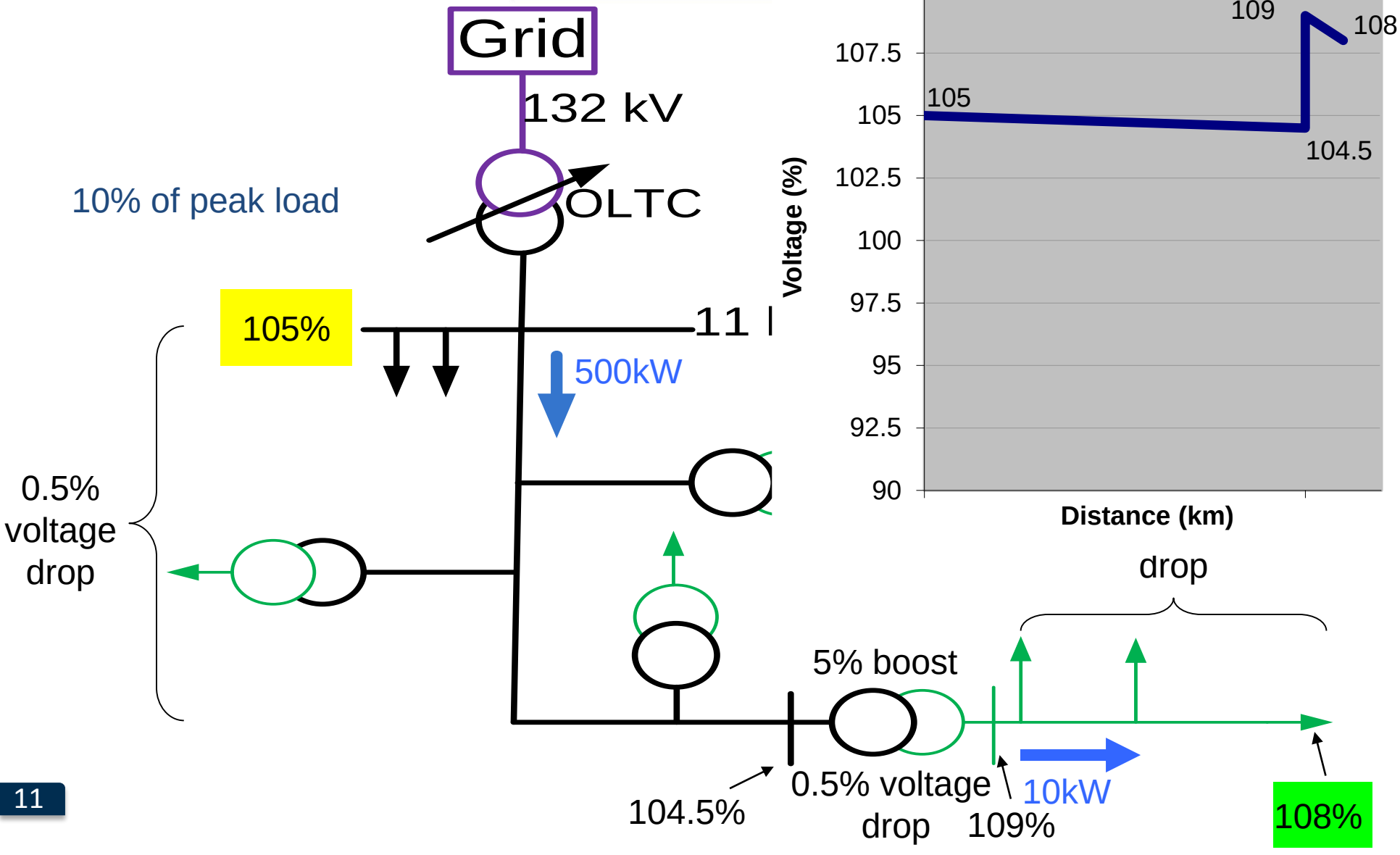
Technical impacts using a simple RSA grid



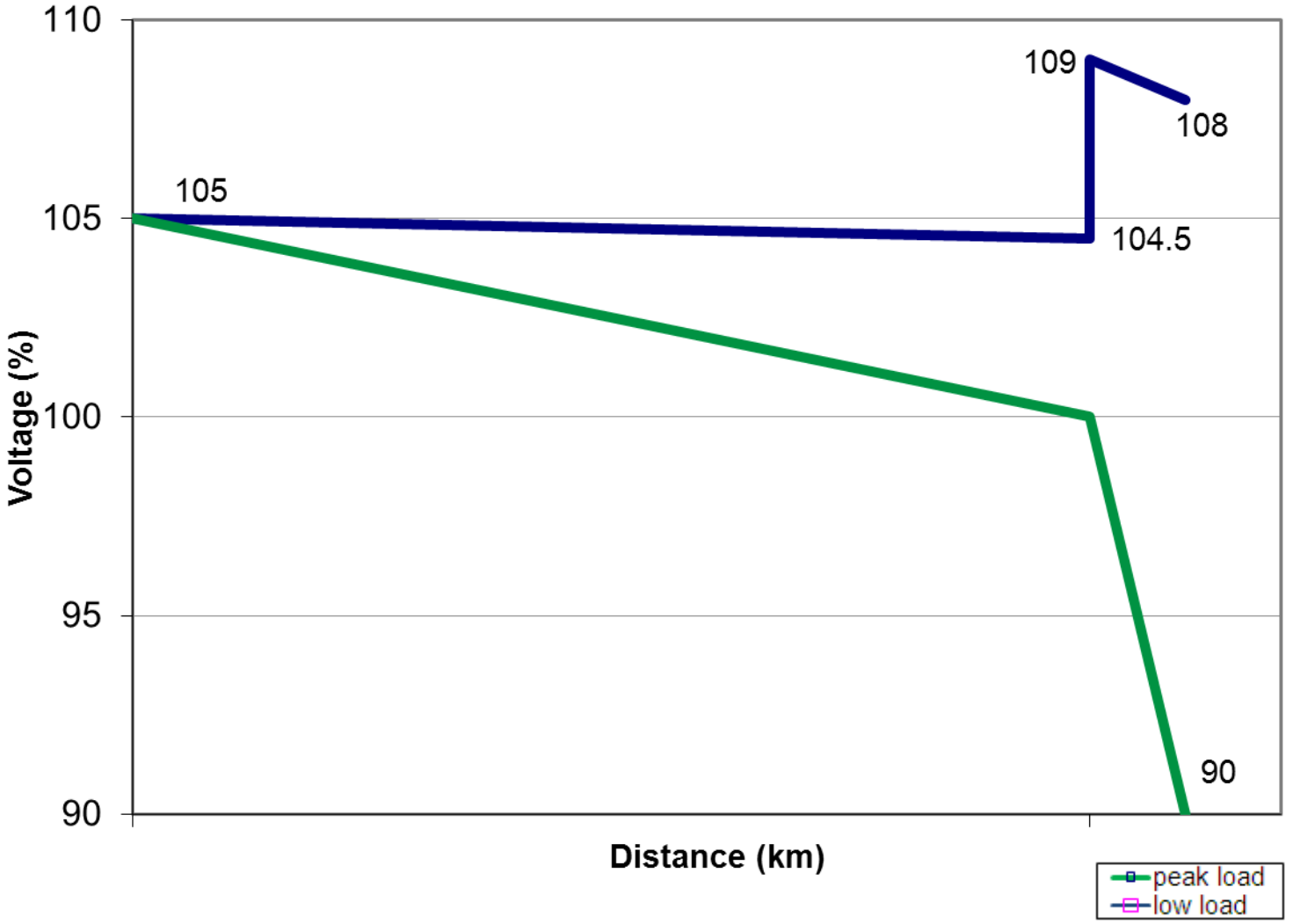
Peak load


Grid
132 kV
OLTC
11 kV
105%
5MW
5%
voltage
drop
10% voltage
drop
5% boost
100%
5% voltage
drop
100%
100kW
90%
110
107.5
105
102.5
100
97.5
95
92.5
90
105
100
90
Voltage (%)
Distance (km)

Low load


Grid
132 kV
OLTC
10% of peak load
105%
500kW
0.5%
voltage
drop
5% boost
drop
104.5%
0.5% voltage
drop
109%
10kW
108%
110
107.5
105
102.5
100
97.5
95
92.5
90
Voltage (%)
105
109
108
104.5
Distance (km)

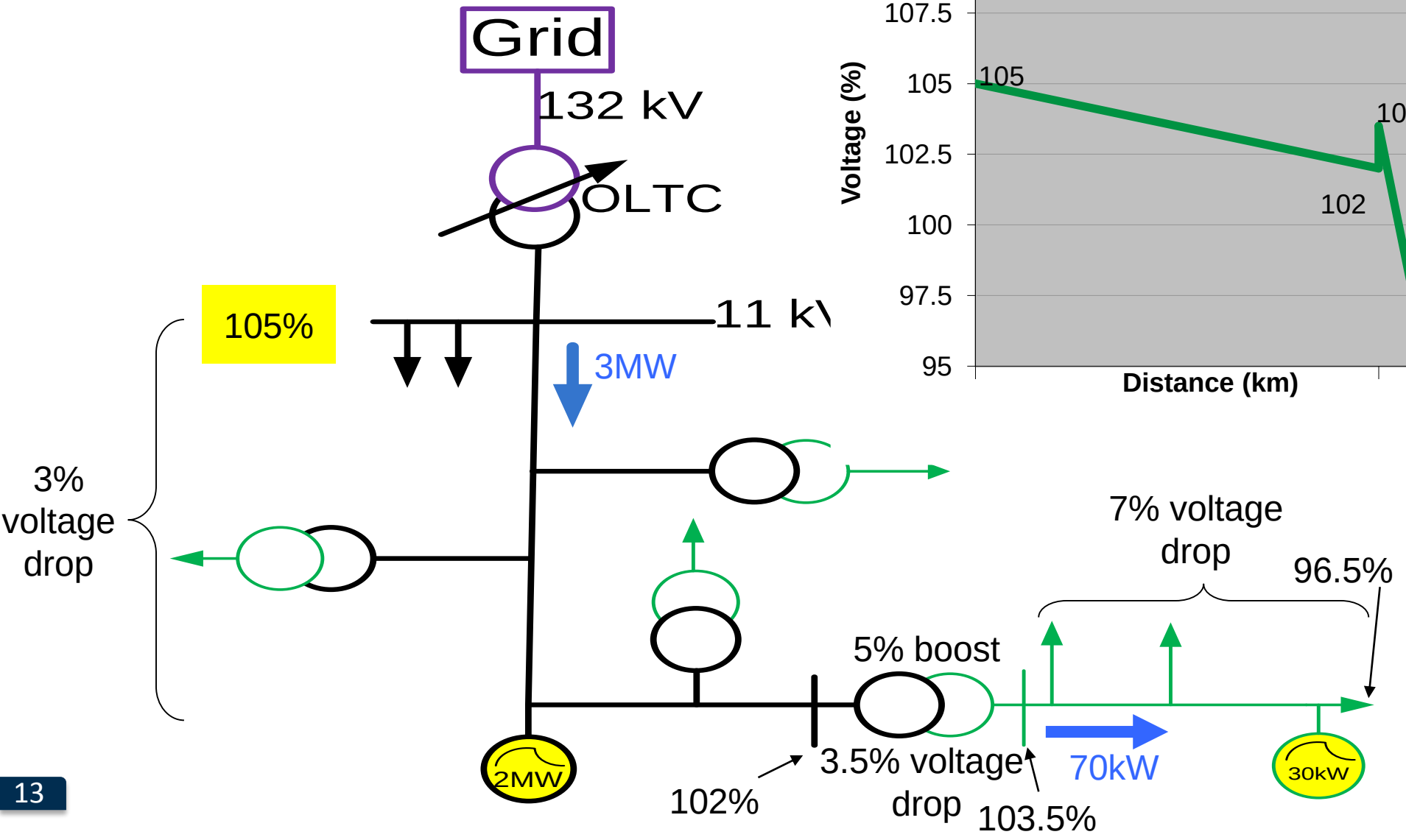
Voltage profiles with no generation



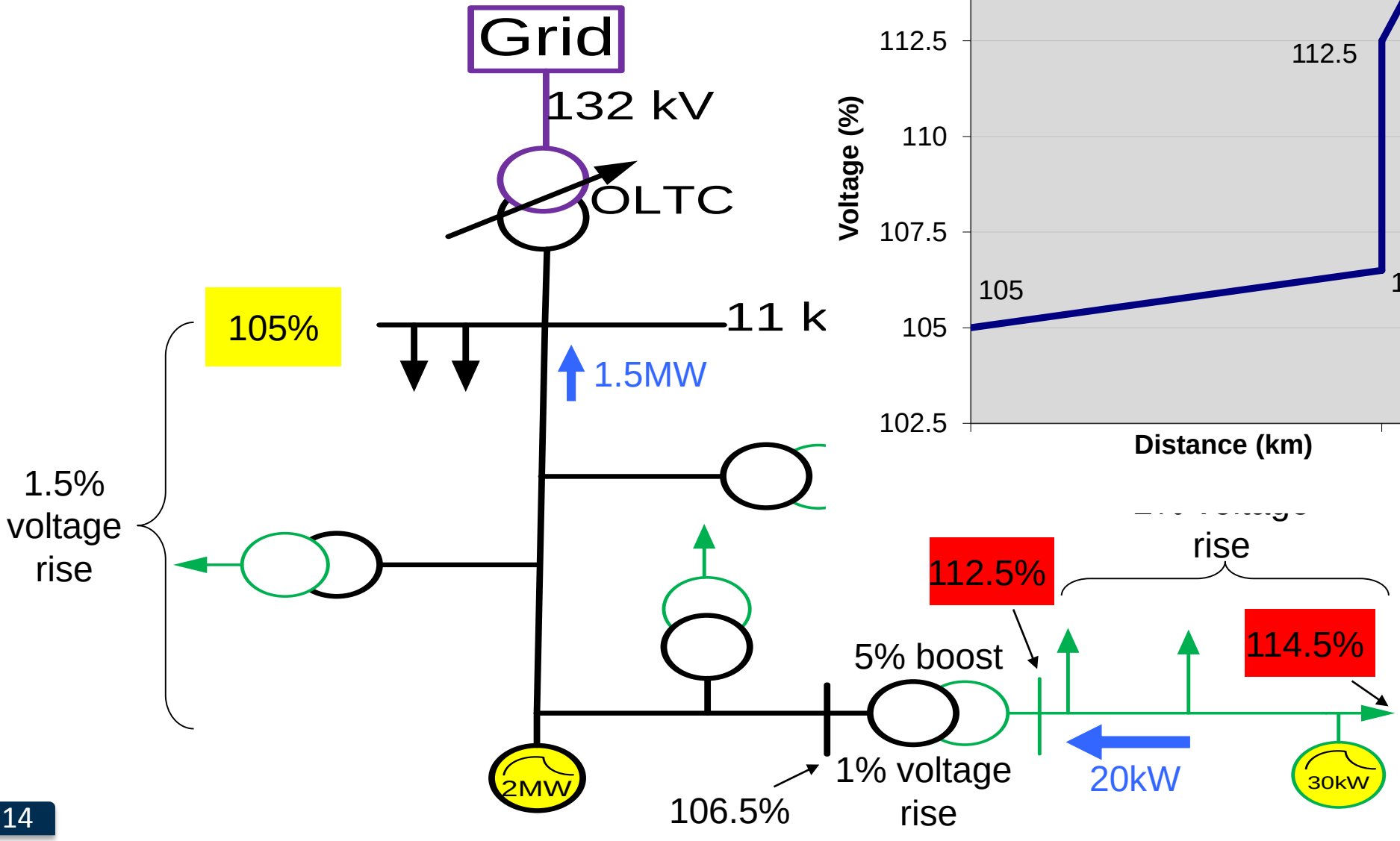
Low load
1% rise
limit

Peak load
15% drop
limit

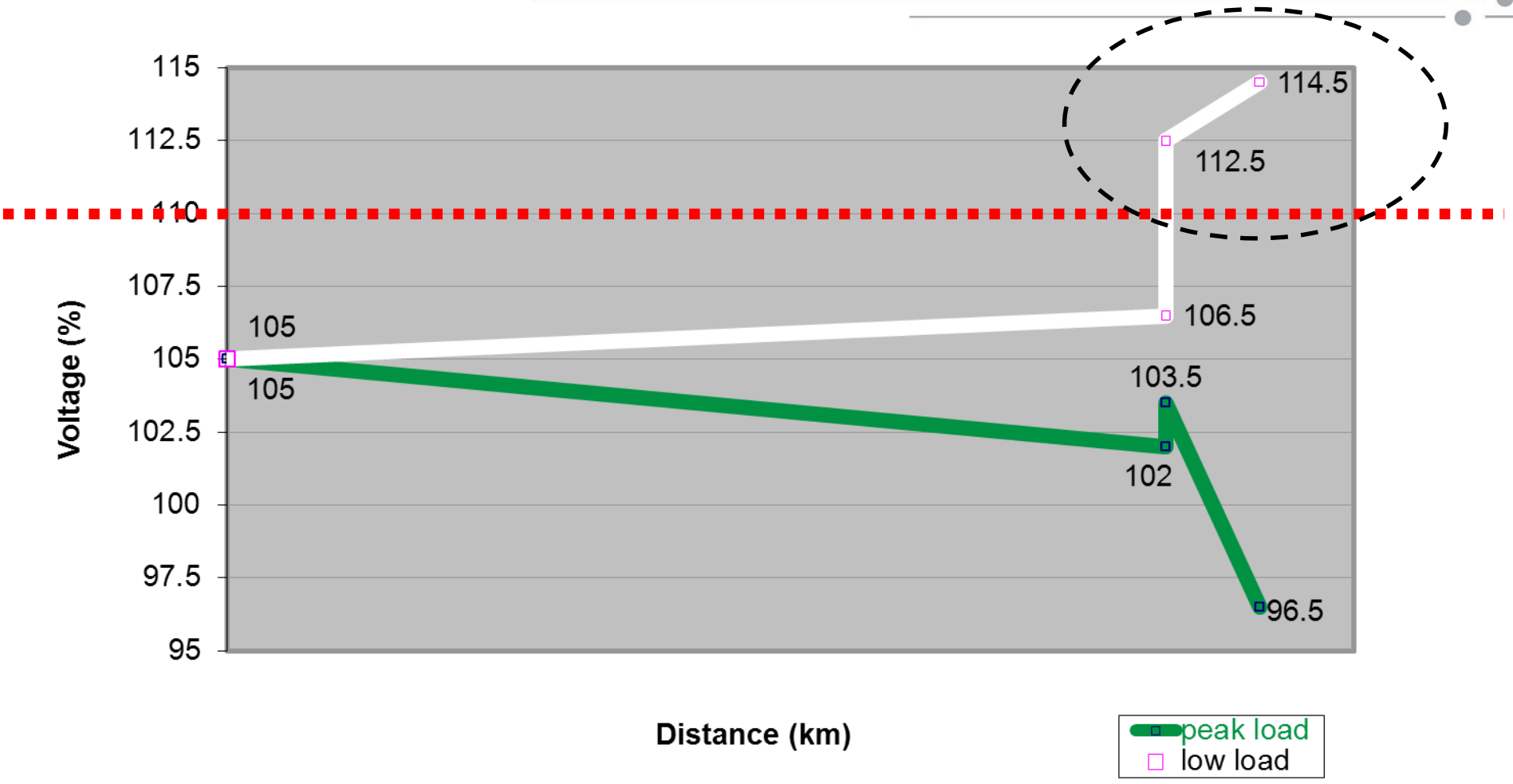
Peak load with generation



Low load with generation

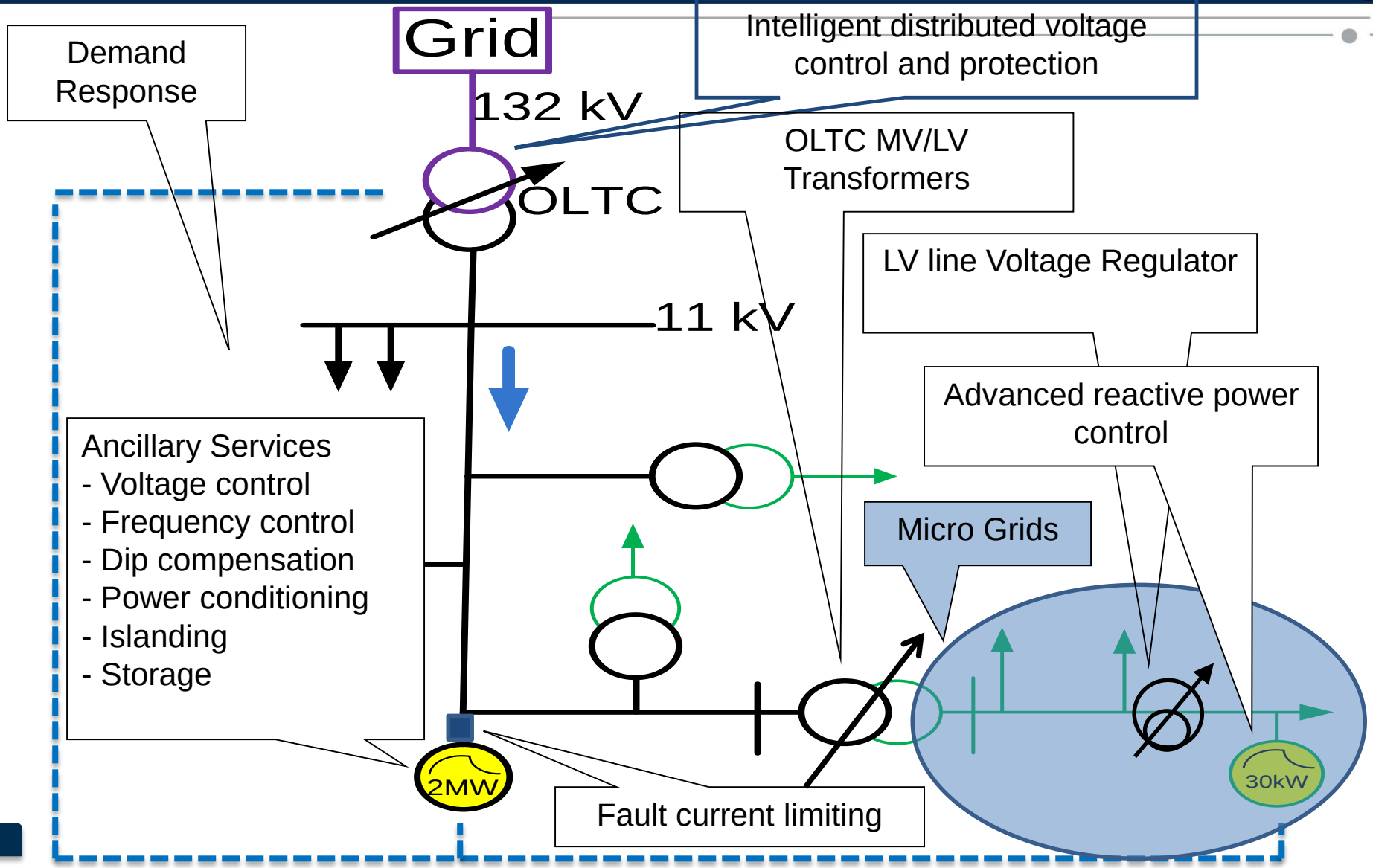


Voltage profiles with generation

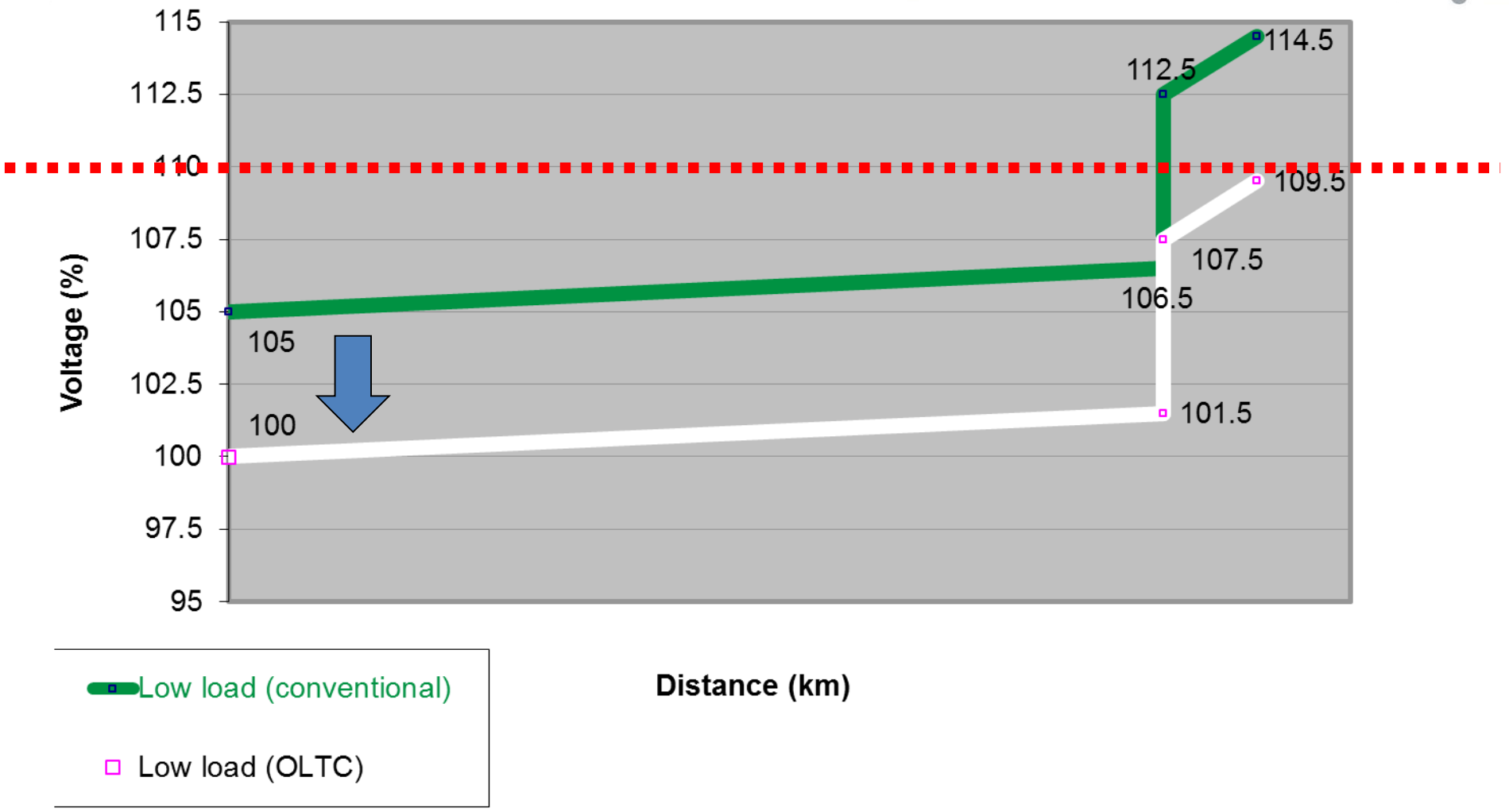


Network can absorb significantly less power than it can supply

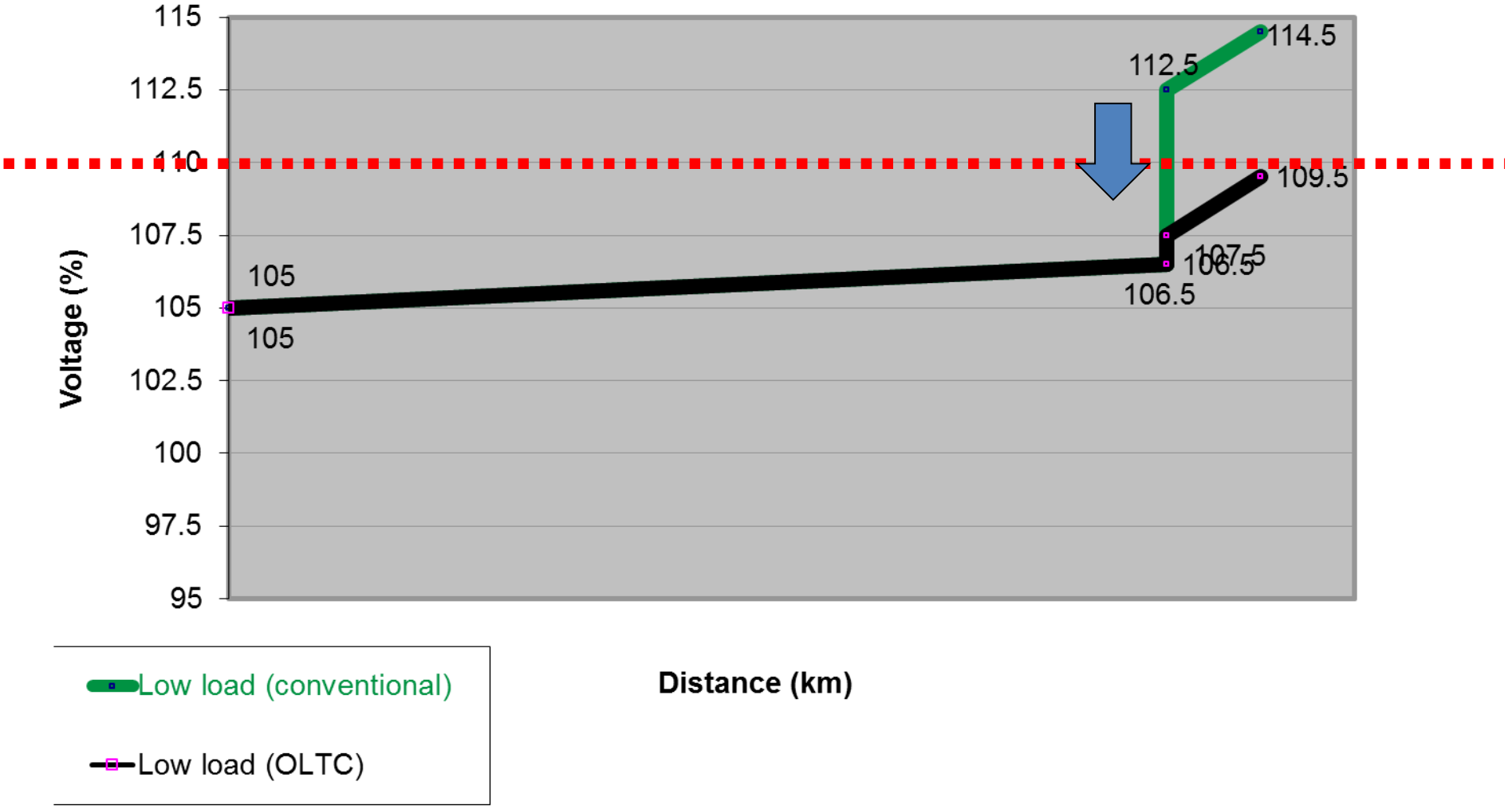
Example Smart Grid solutions



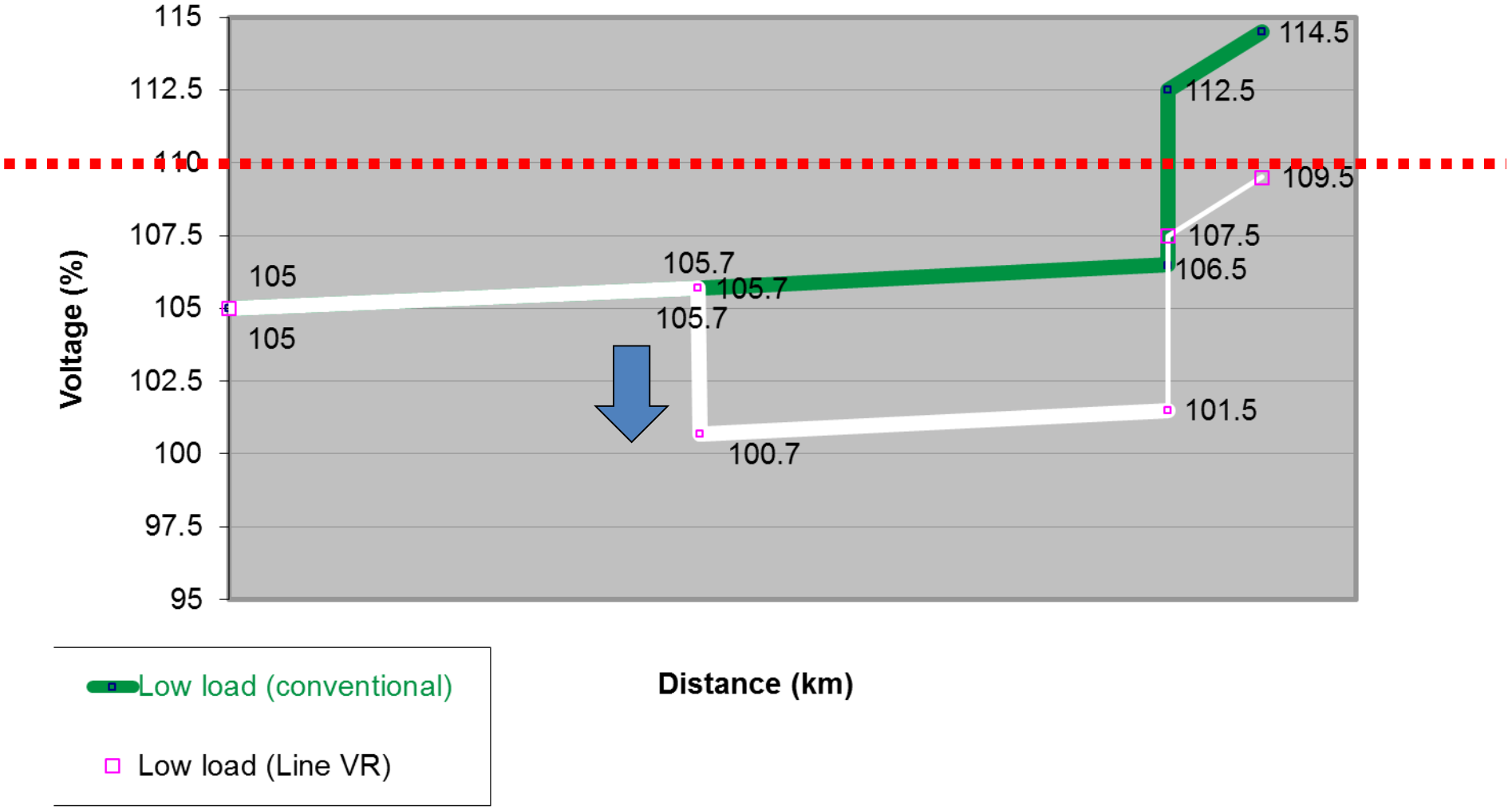
Using OLTC HV/MV transformer to reduce maximum voltages



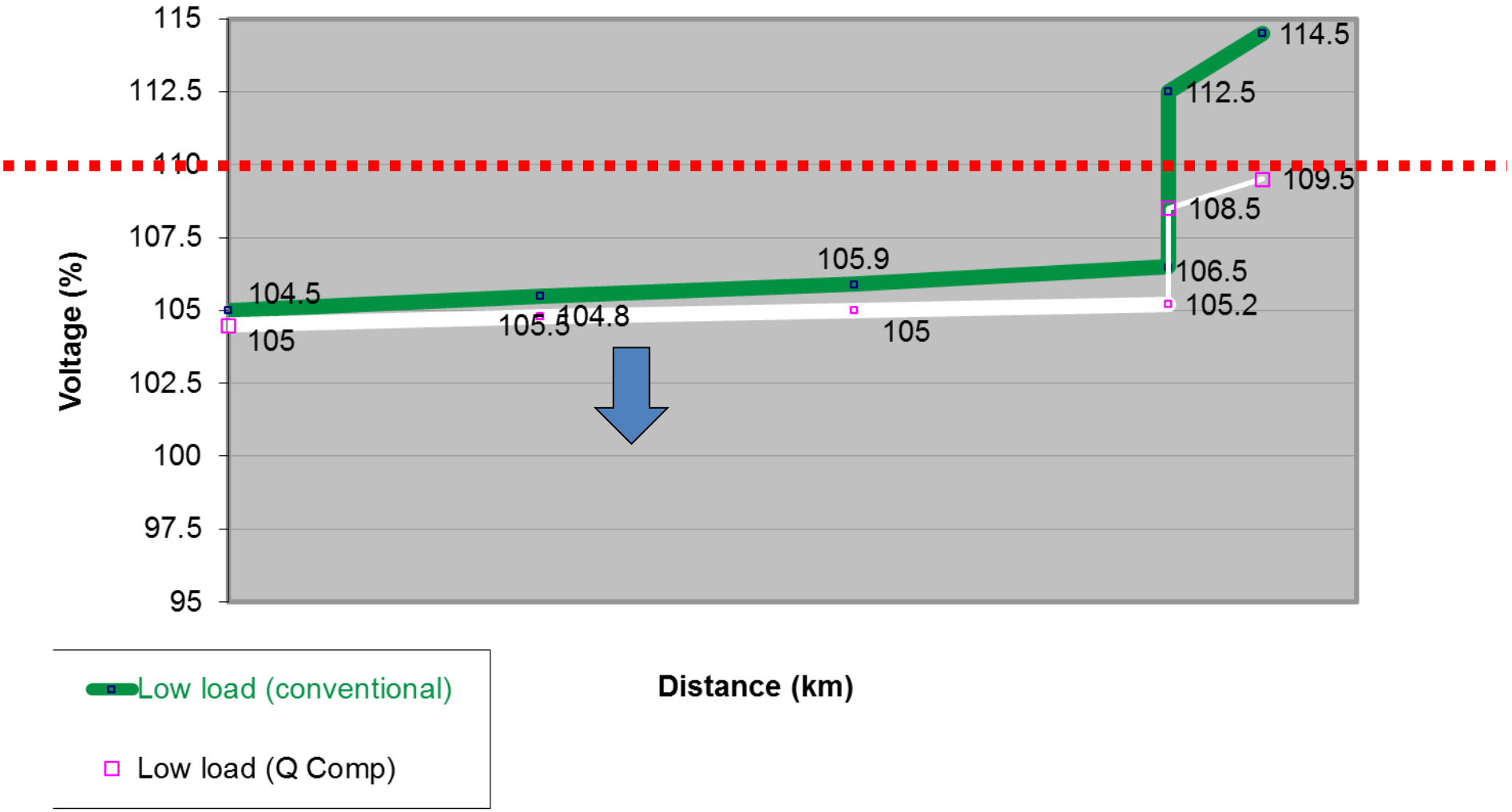
Using OLTC MV/LV transformer to reduce maximum voltages



Using line Voltage Regulator to reduce maximum voltages



Using Reactive Power to reduce maximum LV voltages



NRS 097-2-3

LV connected generation: Simplified connection technical evaluation criteria

NRS 097 series

- **NRS 097-2-1 specifies the minimum technical requirements for LV generators connected to the South African grid**
- **All LV grid connected generator interconnection equipment must be type-test certified, as complying with the minimum technical requirements of NRS 097-2-1**
- **These set of rules will be used to evaluate LV generator grid interconnection applications**
- **LV (230/400V) connected generators falling within these criteria are proposed to follow a simplified connection process that will not require detailed network studies**

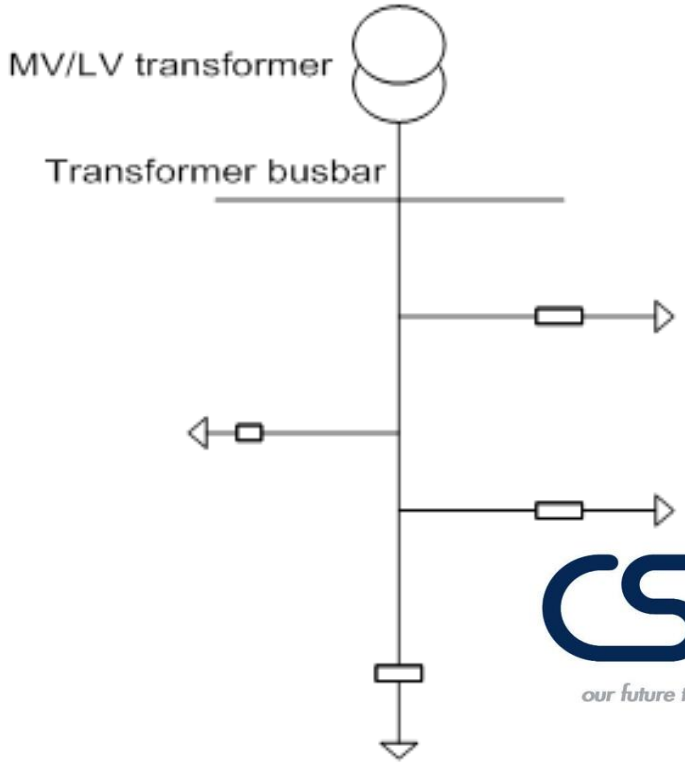
Rules to evaluate LV generator grid interconnection applications

- **Gen sizes > 350 kVA will be connected to MV or HV networks**
- **The maximum permissible generation size of an individual customer is dependent on:**
  - The type of LV network: Depends on whether the LV network supplying the customer is shared (supplies other customers) or dedicated (only supplies the customer in question), and
  - The customers Notified Maximum Demand (NMD): The NMD in many cases is determined by the LV service connection circuit breaker rating.

Shared LV feeders

- **The maximum individual generation limit in a shared LV feeder is 25% of the customer's NMD, up to a maximum of 20kVA (generators >20kVA must be connected via a dedicated LV feeder)**
- **Any generator >4.6kVA must be balanced across 3 ph.**

Number of phases	Service circuit breaker size	NMD (kVA)	Maximum individual generation limit
1	20A	4.6	1.2kVA
1	60A	13.8	3.68kVA
3	60A	41.4	13.8kVA (4.6 kVA per phase)



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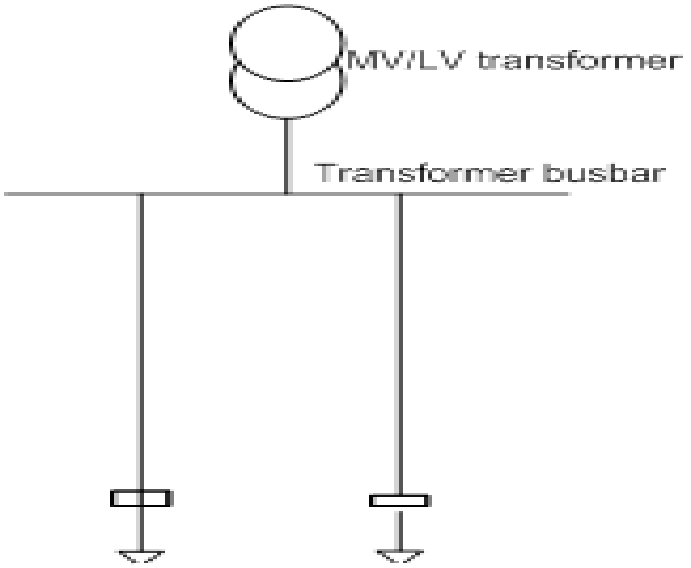
Example of shared LV feeder

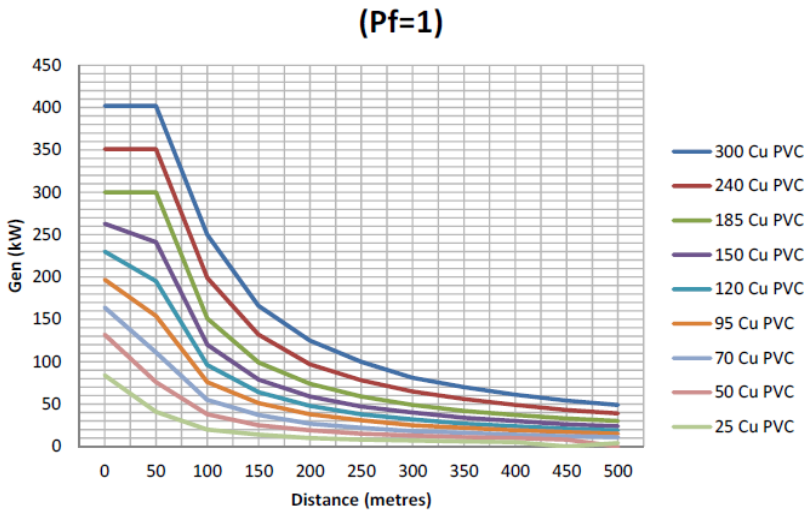
- **A LV customer with a 100kVA NMD supplied via a shared LV feeder could connect up to 100 x 25% = 25kVA of generation. As 25kVA is greater than the 20kVA limit for a shared feeder, the maximum size is 20kVA; which is > than 4.6kVA 1-ph limit; it would need to be 3-ph connected.**
  - If the maximum individual generation limit is exceeded, the customer could potentially be connected via a dedicated LV feeder, paid for by the customer such that the generator is supplied via a dedicated LV feeder (and the dedicated LV feeder limits apply).
  - The total generation supplied by shared LV feeders is limited to 25% of the MV/LV transformer rating.
- **A 200kVA MV/LV transformer can supply up to 50kVA of generation supplied via shared LV feeders connected to that transformer.**

Dedicated LV feeders

The maximum individual generation limit is a function of:

- **The Notified Maximum Demand: The maximum generator size is limited to 75% of the NMD**
- **Single phase supplies max gen 13.8kVA**
- **Multi-phase supplies all generators > 4.6kVA must be balanced**
- **Connections that only supply generators will be made via a dedicated LV feeder**
- **The dedicated feeder cable size (voltage rise is limited to 1%)**

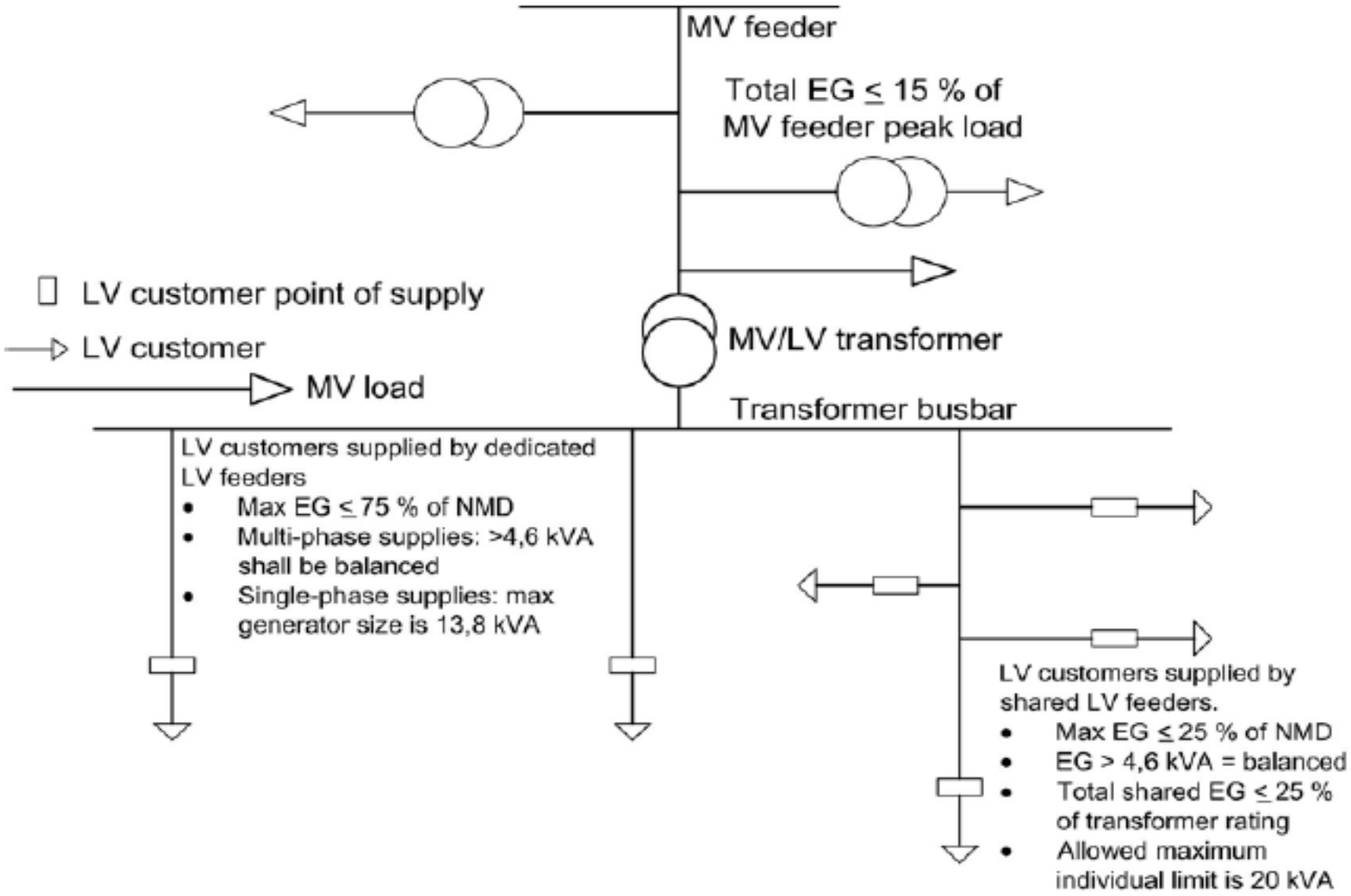




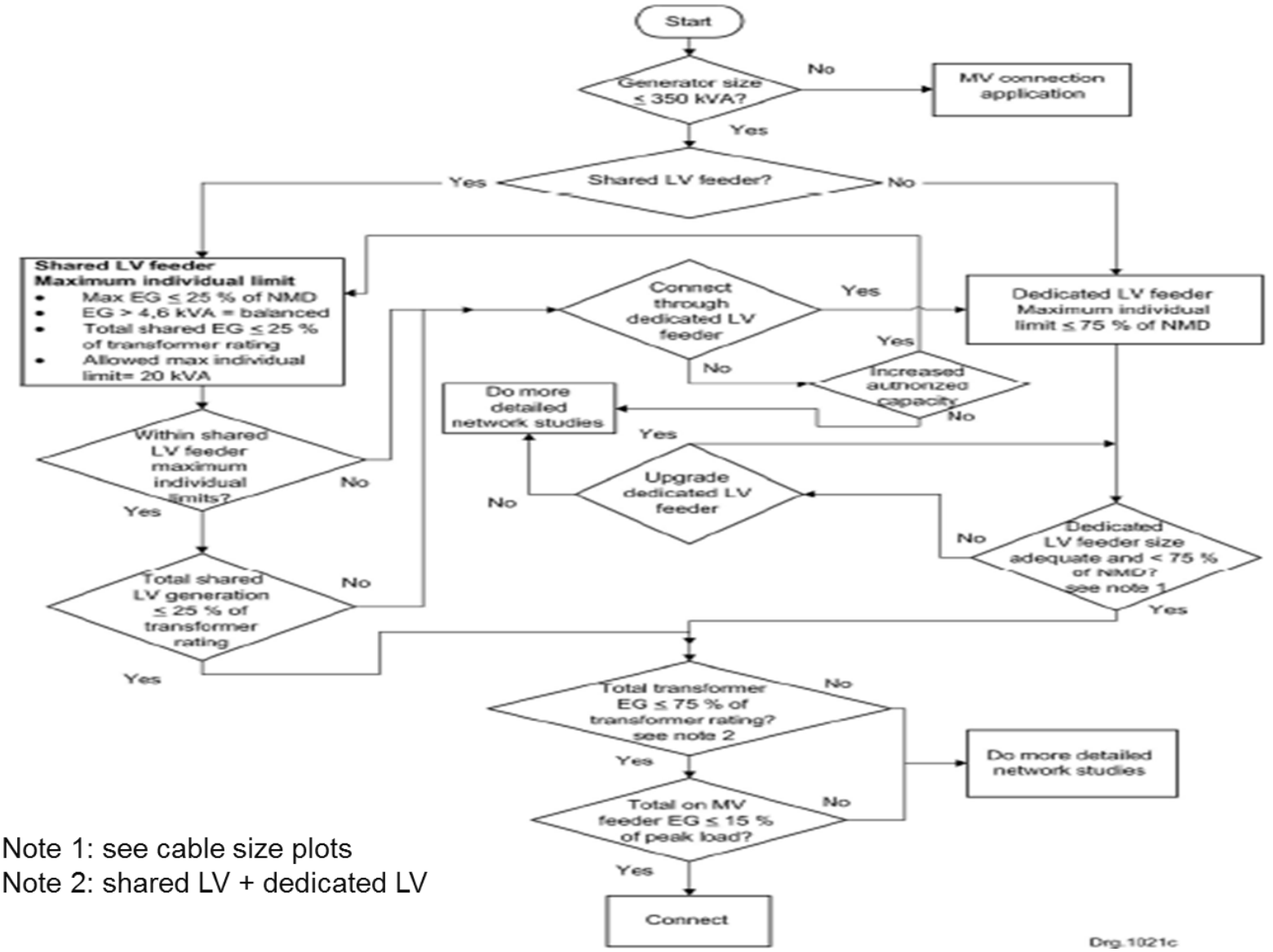
Additional rules

- **The following rules apply in addition to the rules for shared and dedicated LV feeder connected generators:**
  - The total generation (i.e. shared LV generation + dedicated LV generation) supplied by a MV/LV transformer shall be less than 75% of the MV/LV transformer rating, and
  - The total generation supplied by a MV feeder shall be less than 15% of the MV feeder peak load.
- **If both criteria are not met, then additional generation does not meet the simplified connection criteria; hence cannot be connected to the network without further studies**

Summary of the connection criteria



Flow chart



Note 1: see cable size plots
Note 2: shared LV + dedicated LV

Re a leboha

Ha Khensa

Enkosi

Siyathokoza

Thank you

Re a leboga

Ro livhuha

Dankie

Siyabonga

Note: “Thank you” in all official languages of the Republic of South Africa