Lösungen zur Spannungsregelung in Verteilernetzen

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Agenda

- Traditional and future structure of the distribution grid
- Impacts on grid voltage
- Case Study: STATCOM operation of PV – Central Inverters
- Case Study 2: Voltage control by series regulator
- Summary and conclusion

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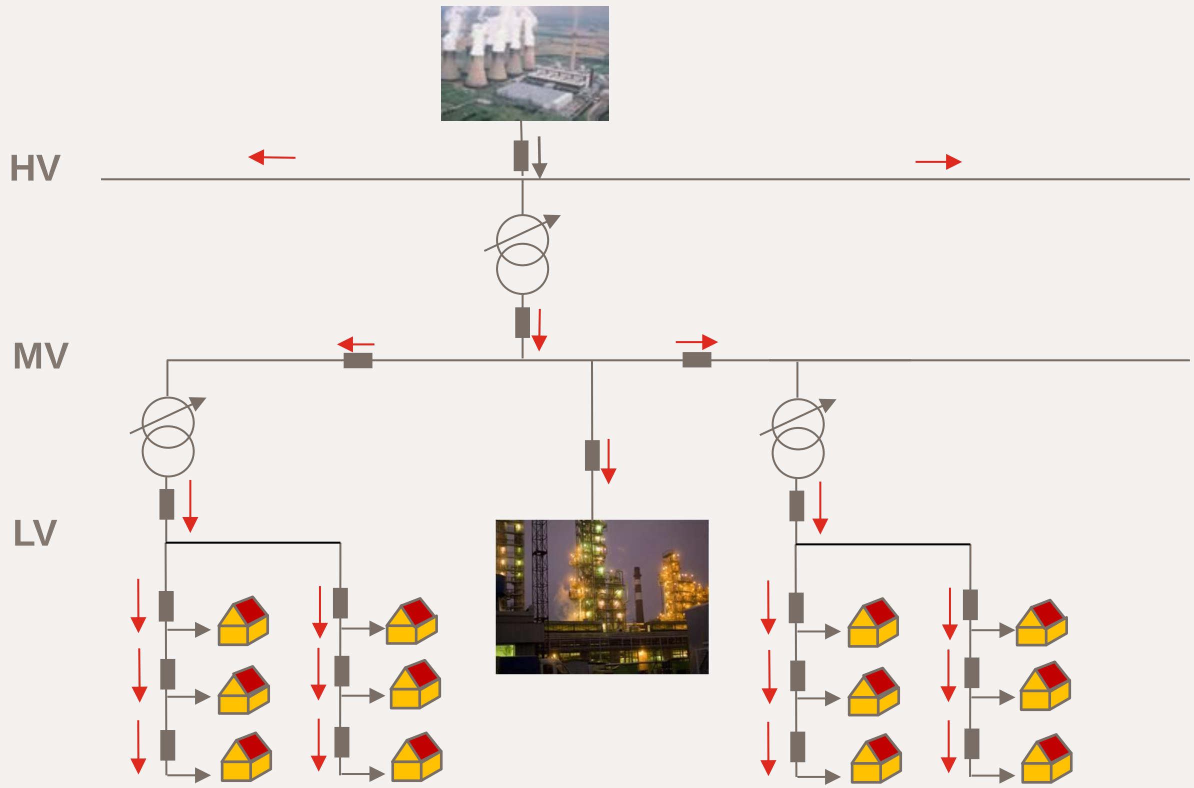
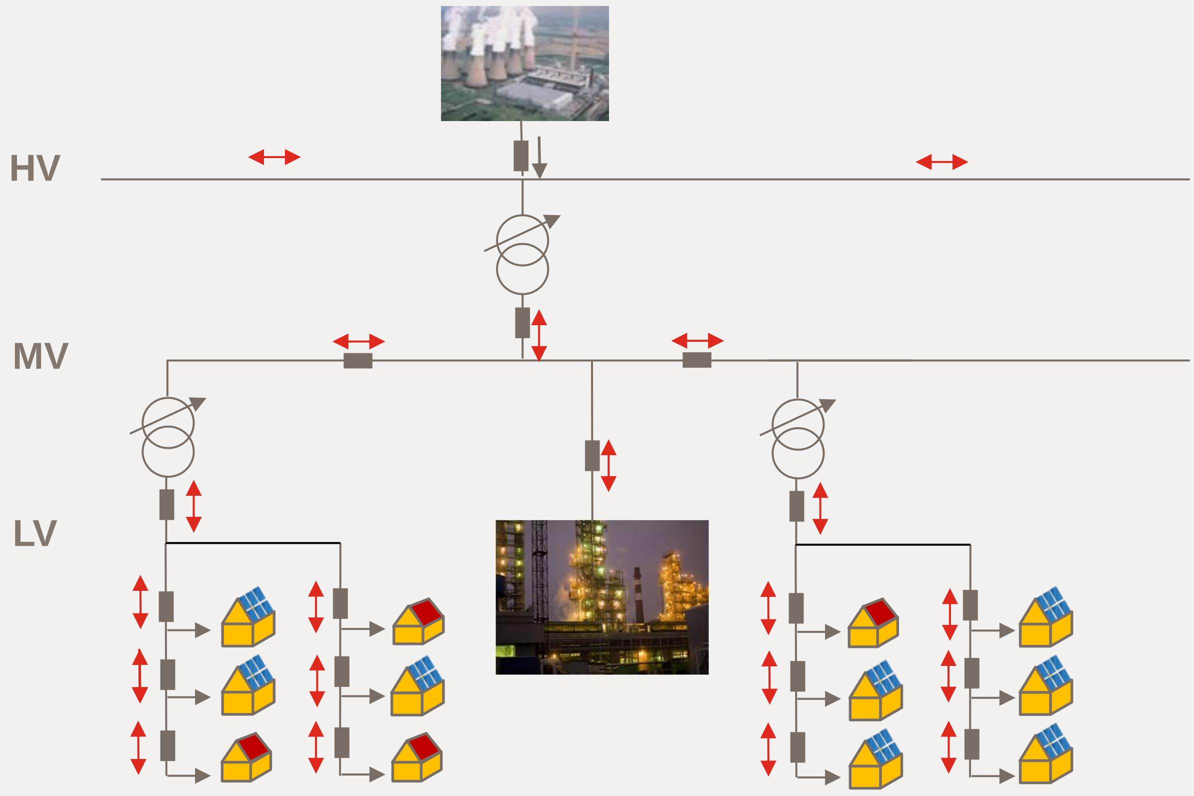
Structure of the traditional Distribution Grid



- Straight forward top down structure
- Unidirectional power flow from PCC to the loads
- Unidirectional voltage drop
- Load balancing basically provided by the grid

Restructuring of the Distribution Grid



- Bi-directional Power Flow ⇒ Bi-directional Voltage Drop across distribution lines
- Long single feeders, temporarily unloaded lead to increased reactive power consumption
- Highly fluctuating renewable power generation adds on existing volatile load characteristics ⇒ increased variability of line voltage drop

Required: dynamic & active voltage control
dynamic reactive power compensation (inductive/capacitive)

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Normative Requirements for Voltage Quality in Germany

EN 50160	Werte bzw. Wertebereiche		Mess- und Auswerteparameter			
	Niederspannung	Mittelspannung	Basisgröße	Integrationsintervall	Beobachtungsperiode	Prozentsatz
Frequenz (bei Verbindung zu einem Verbundnetz)	49,5 Hz bis 50,5 Hz 47 Hz bis 52 Hz		Mittelwert	10 s	1 Woche	95% 100%
Langsame Spannungsänderungen	230 V ± 10 %	U_c ± 10 %	Effektwwert	10 min	1 Woche	95%
Schnelle Spannungsänderungen	5% max. 10 %	4% max. 6 %	Effektivwert	10 ms	1 Tag	100%
Flicker (Festlegung nur für Langzeitflicker)	$P_{lt} = 1$		Flickeralgorithmus	2 h	1 Woche	95%
Spannungseinbrüche (≤ 1min)	einige 10 bis 1000 pro Jahr (unter 85 % U_c)		Effektivwert	10 ms	1 Jahr	100%
Kurze Versorgungs- unterbrechungen (≤ 3 min)	einige 10 bis mehrere 100 pro Jahr (unter 1 % U_c)		Effektivwert	10 ms	1 Jahr	100%
Zufällige lange Versorgungsunterbrechungen (> 3 min)	einige 10 bis 50 pro Jahr (unter 1 % U_c)		Effektivwert	10 ms	1 Jahr	100%
Zeitweilige netzfrequente Überspannungen (Außenleiter - Erde)	meist < 1,5 k V	1,7 bis 2,0 (je nach Sternpunktbehandlung)	Effektivwert	10 ms	keine Angabe	100%
Transiente Überspannungen (Außenleiter - Erde)	meist < 6 kV	entsprechend der Isolationskoordination	Scheitelwert	kein	keine Angabe	100%
Spannungsunsymmetrie (Verhältnis Gege- zu Mitsystem)	meist 2 % in Sonderfällen bis 3 %		Effektivwert	10 min	1 Woche	95%
Oberschwingungsspannung (Bezugswert U_n bzw. U_c)	Gesamtoberschwingungsgehalt (THD) 8%		Effektivwert	10 min	1 Woche	95%
Zwischenharmonische Spannung	Werte in Beratung		Werte in Beratung			
Signalspannungen (Bezugswert U_n bzw. U_c)	Bereich 9 bis 95 kHz in Beratung		Effektivwert	3s	1 Tag	99%

Source: B&W Tech Comp

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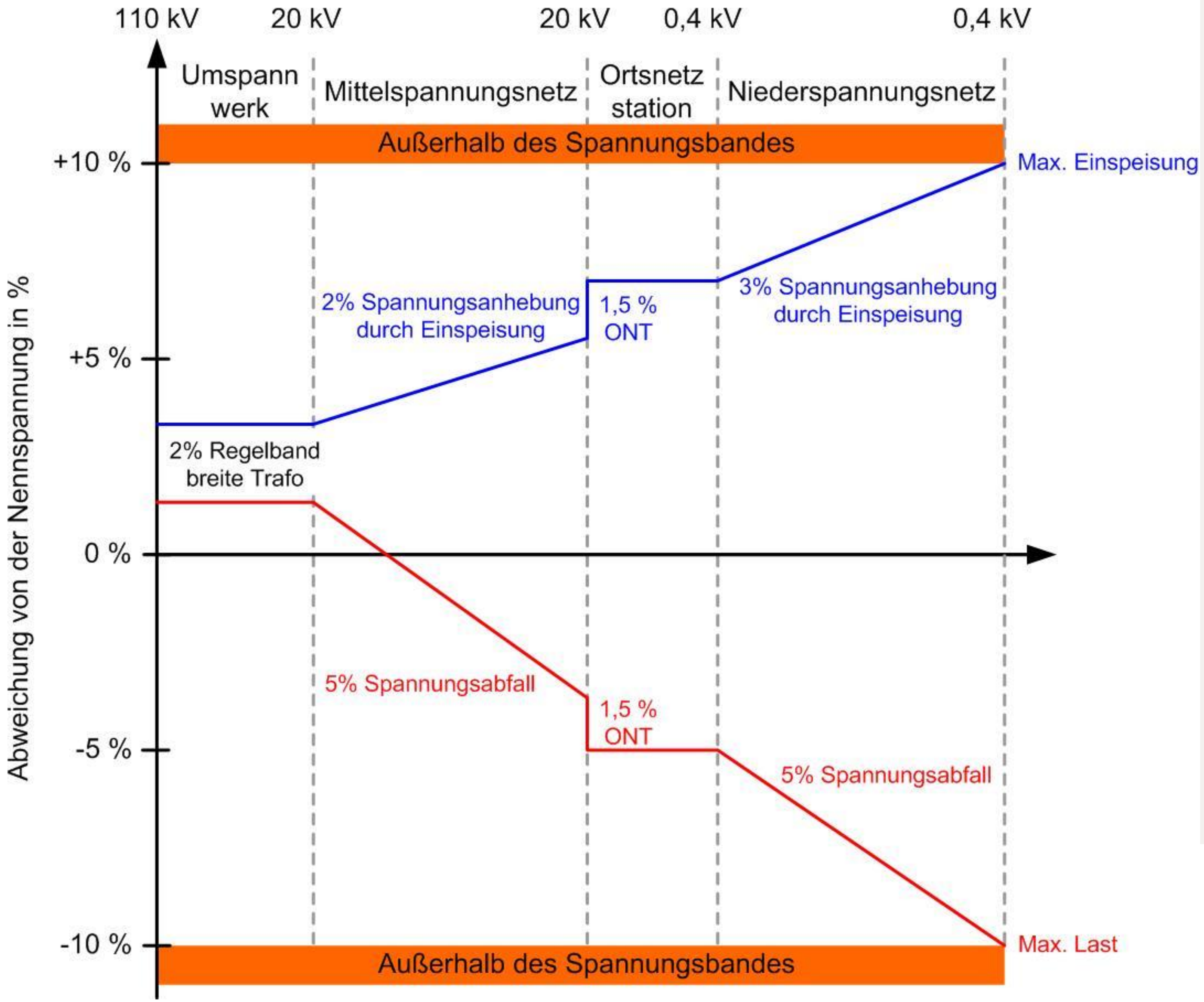
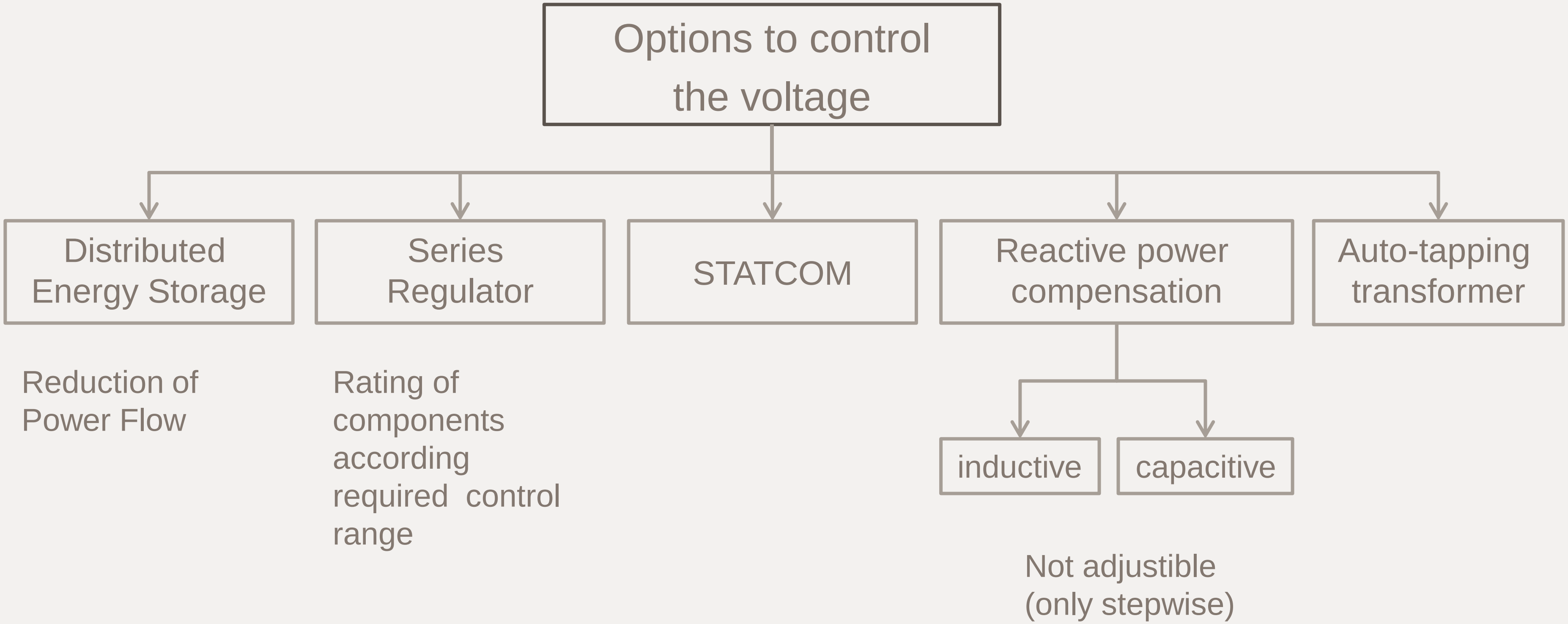
Grid voltage for different load scenarios



Restructuring of the Distribution Grid



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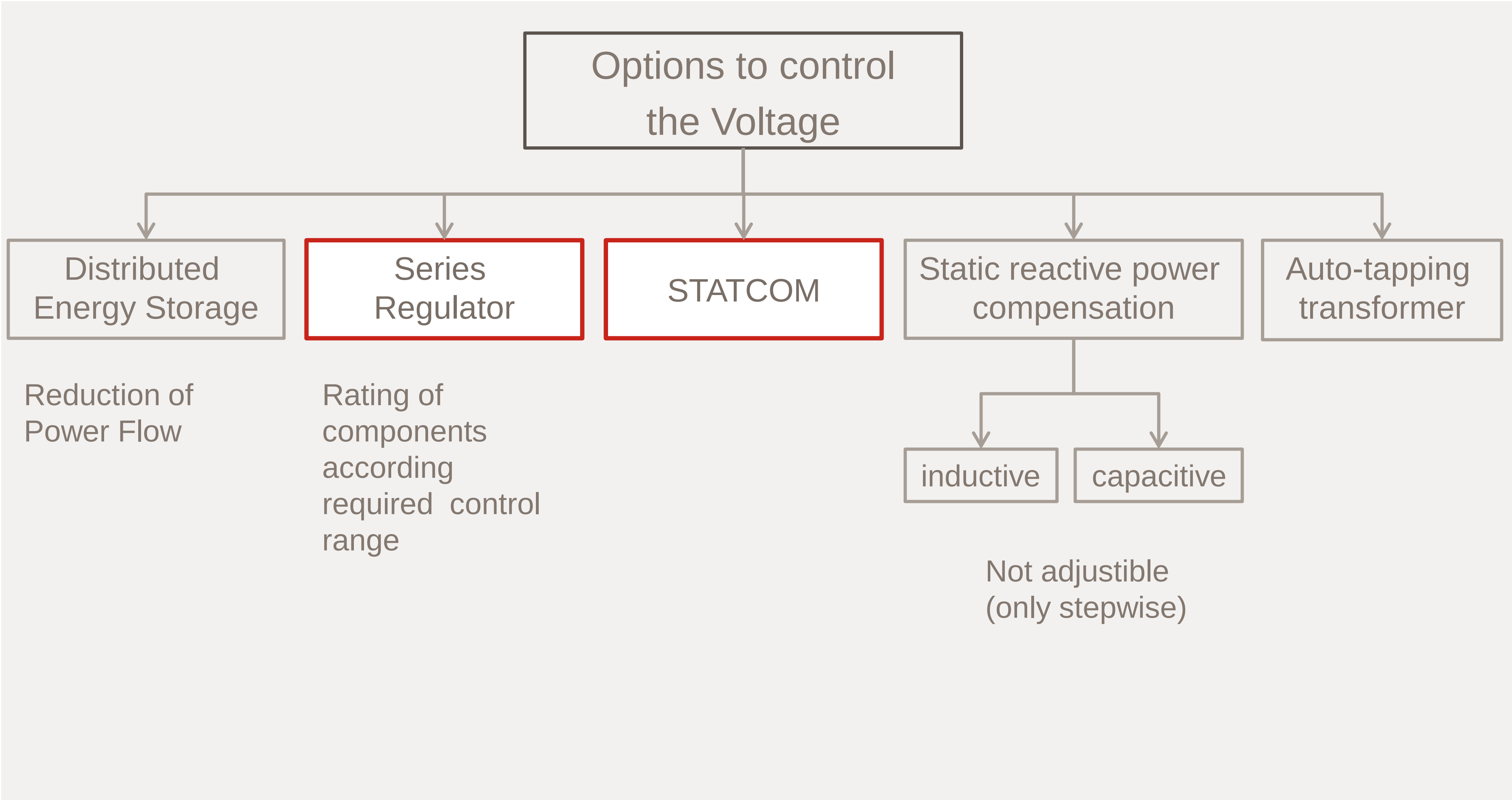
Restructuring of the Distribution Grid



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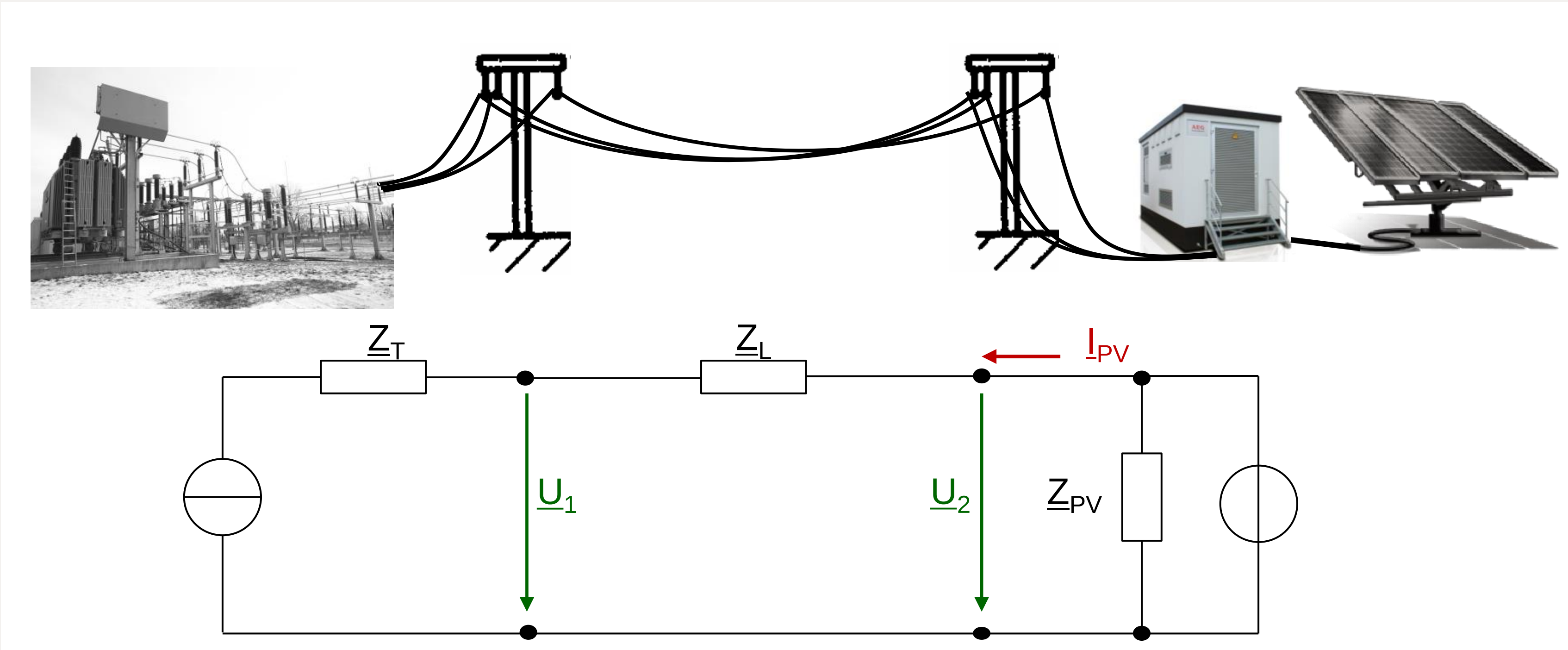
Benefit of feeding in reactive power



Transformer (Grid)

Voltage Source

$$\underline{U}_1 = U_1 \cdot e^{j0^\circ}$$

Transmisson Line

(Lossy Line)

$$\underline{Z}_L = Z_L \cdot e^{j\theta}$$

$$\theta = \cos^{-1}\frac{R}{X}$$

PV Generator

Current Source

$$\underline{I}_{PV} = I_{PV} \cdot e^{j\varphi}$$

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Benefit of feeding in reactive power

$$\underline{U}_2 = \underline{U}_1 + \underline{U}_{ZL}$$

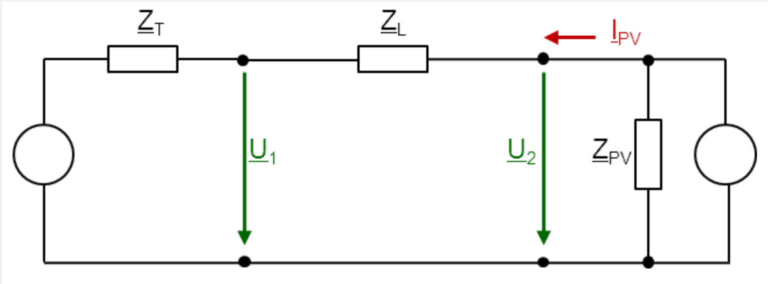
$$\underline{U}_2 = \underline{U}_1 + I_{PV} \cdot Z_L \cdot e^{j(\varphi+\theta)}$$

$$\underline{U}_2 = \underbrace{U_1 + I_{PV} \cdot Z_L \cdot \cos(\varphi+\theta)}_{\text{RE}} + \underbrace{j\, I_{PV} \cdot Z_L \cdot \sin(\varphi+\theta)}_{\text{IM}}$$

$$|\underline{U}_2| = \sqrt{(U_1 + I_{PV} \cdot Z_L \cdot \cos(\varphi+\theta))^2 + (I_{PV} \cdot Z_L \cdot \sin(\varphi+\theta))^2}$$

$$|\underline{U}_2| = \sqrt{{U_1}^2 + 2U_1 \cdot I_{PV} \cdot Z_L \cdot \cos(\varphi+\theta) + (I_{PV} \cdot Z_L)^2}$$

Optimization Parameter!



Only cos(φ) can be changed to influence Voltage at point of common coupling

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Benefit of feeding in reactive power

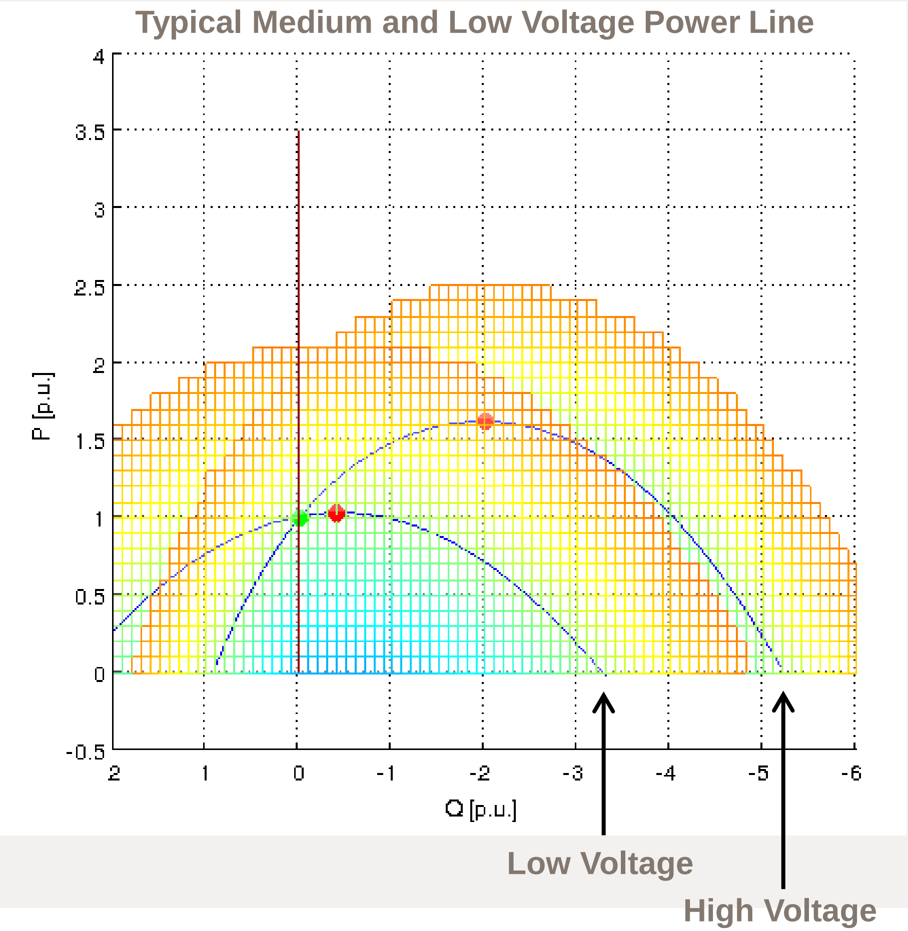
Comparison of STATCOM use in low and medium voltage grid:

- STATCOM has stronger effects when the reactance of a power line is high
- Low voltage grid lines have primarily resistance, so the effects of STATCOM are limited

Typical power line parameter

	Spannungsniveau	R $[\Omega/km]$	X $[\Omega/km]$	I_n $[A]$	$\frac{R}{X}$
LV	Niederspannung	0,642	0,083	142	7,7
MV	Mittelspannung	0,161	0,190	396	0,85
	Hochspannung	0,06	0,191	580	0,31

Source: http://www.uni-kassel.de/upress/online/frei/978-3-89958-377-9.volltext.frei.pdf



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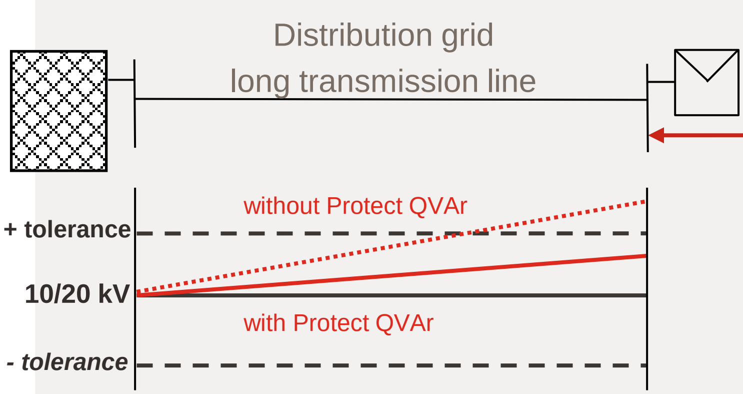
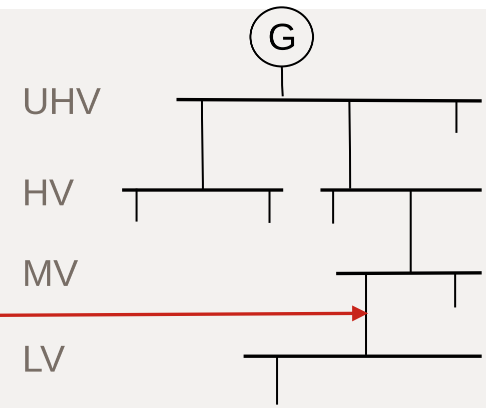
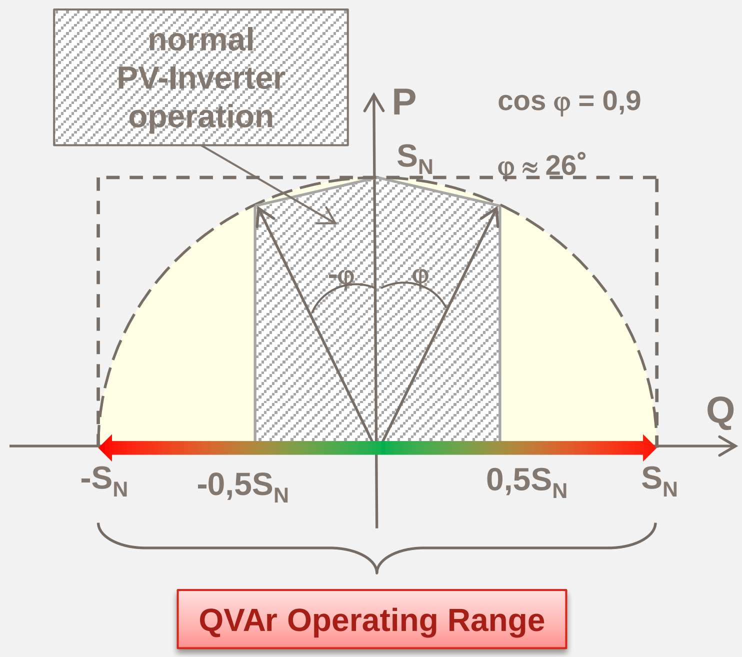
Case Study: STATCOM Operation of PV – Central Inverters





Grid voltage regulation

- Tech. relevant for distribution grids
- Voltage band violation due to reverse power flow
- Avoidance of expensive grid extension measures



Reduction of reactive power consumption

- Increased reactive power demand of distribution grid due to renewable energy generation
- Avoidance og high penalty payments of DSO

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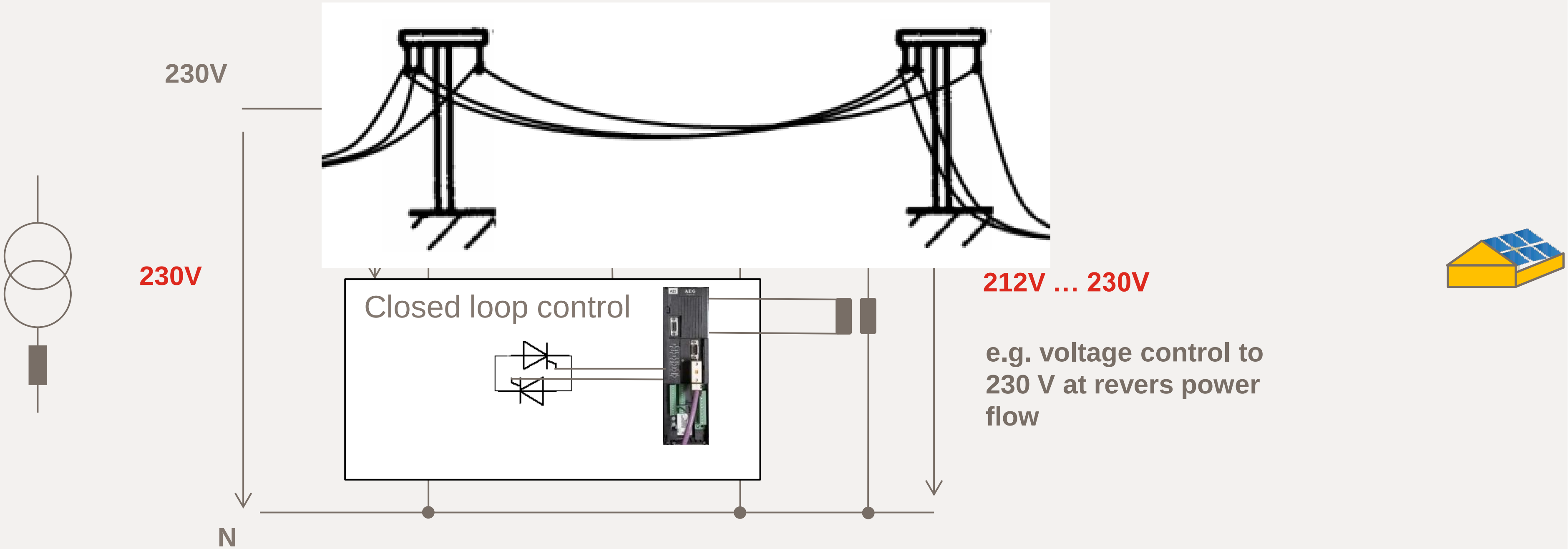
Case Study 2: Voltage Control by series regulator

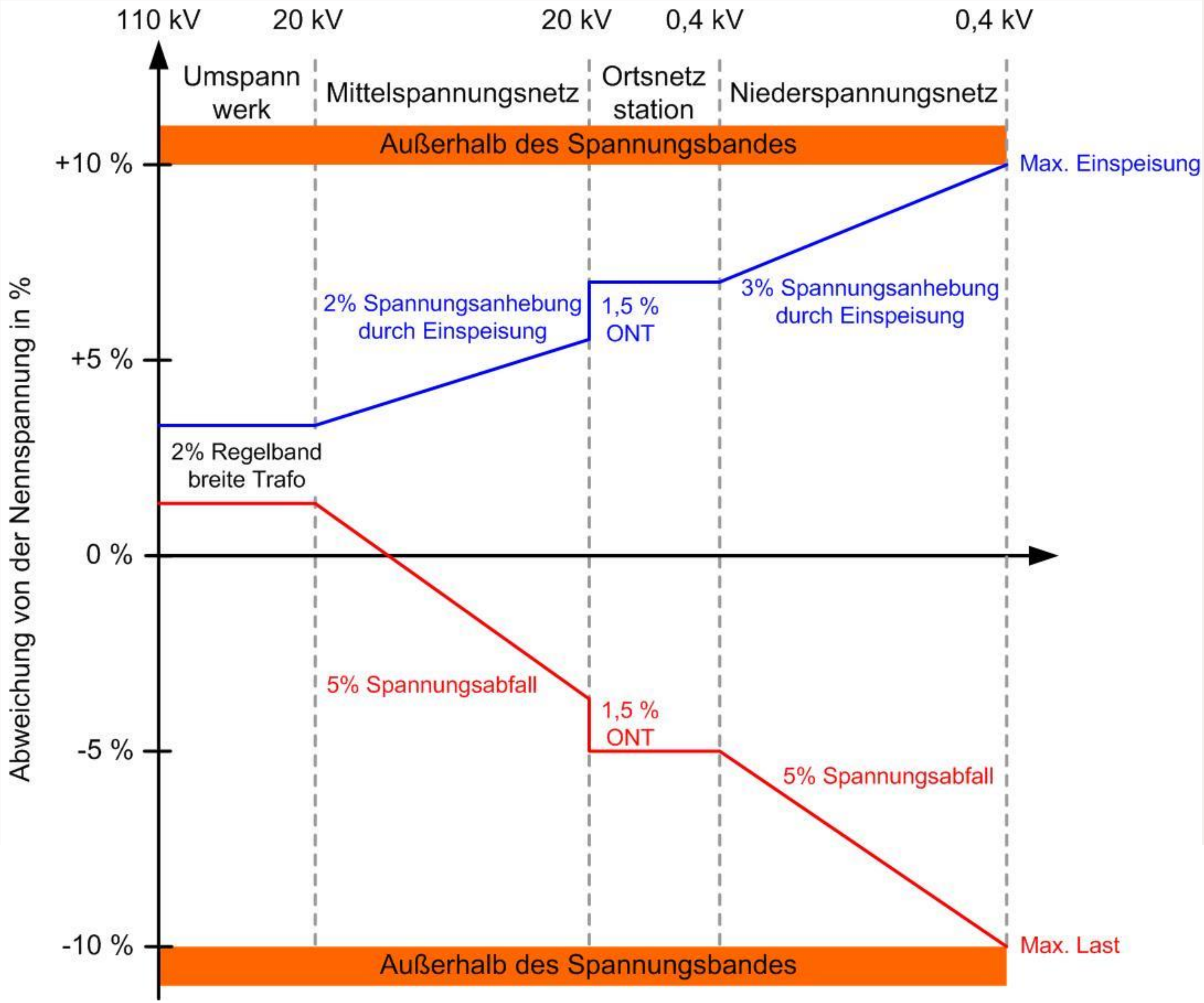
Voltage reduction by three-phase series regulator

- Transformer with 2 tappings
- Step less adjustment of voltage by voltage sequence control (VSC)
- Control range 0 to -8%



Single line equivalent circuit diagram

Grid voltage for different load scenarios



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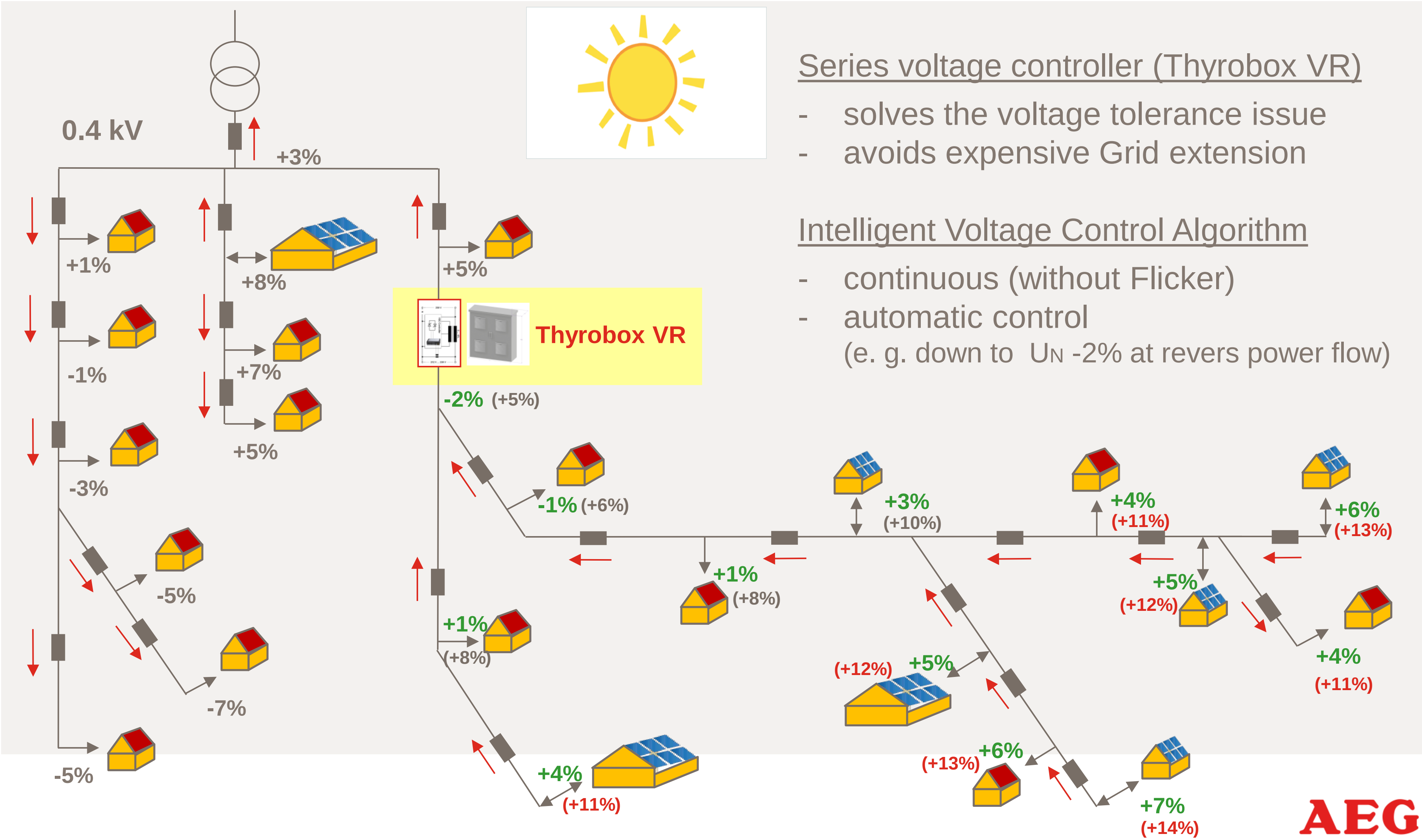
Case Study 2: Voltage Control by series regulator



Series voltage controller (Thyrobox VR)

- solves the voltage tolerance issue
- avoids expensive Grid extension

Intelligent Voltage Control Algorithm

- continuous (without Flicker)
- automatic control
  (e. g. down to U_N -2% at revers power flow)

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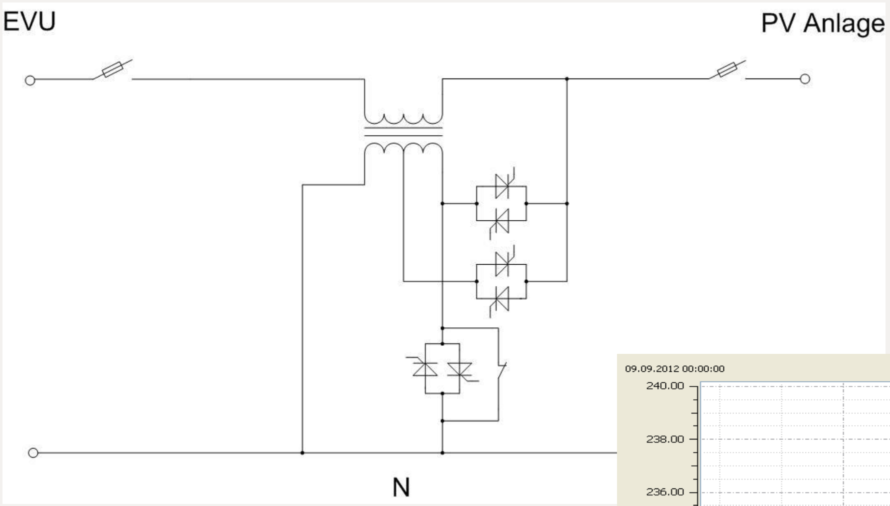
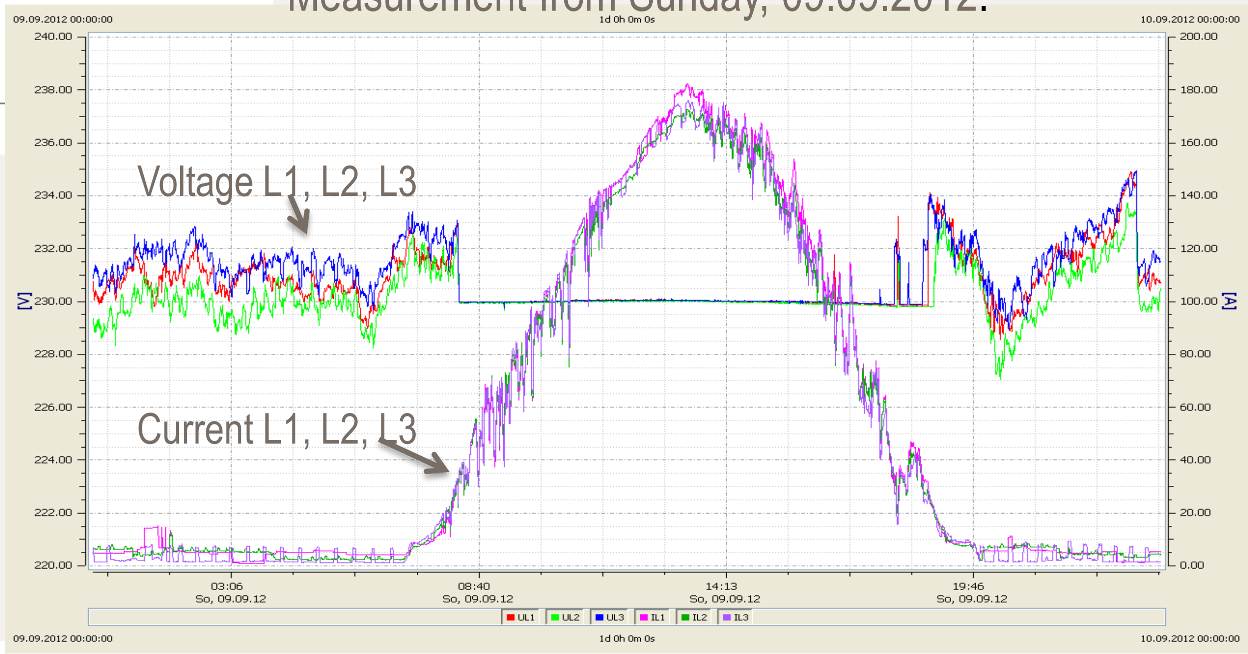
Case Study 2: Voltage Control by series regulator



- Implemented with „Stadtwerke Lippstadt“
- 125 kVA or 250 kVA
- Efficiency: 99,5% at full load

Measurement from Sunday, 09.09.2012.



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Case Study 2: Voltage Control by series regulator

Series voltage regulator (Thyrobox VR)

- **Continuous voltage control - no switching required**
- **Reliable thyristor technology at efficiencies >99%**
- **Space saving design to allow assembly near footways, bicycle paths and roads**

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Summary and Conclusion

- The line voltage in distribution grids is more and more exceeding the limits of the voltage tolerance band due to high penetration of renewable power generation
- To avoid expensive grid extension several intelligent voltage control options are available
- A STATCOM is an appropriate device to control the voltage in medium voltage distribution grids by means of dynamic injection of reactive power as requied
- A series voltage regulator is an appropriate device to control the voltage in low voltage distribution grids; specifically in case of long single feeders

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Thank you

for your attention!

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