Introduction to
Empowerment
with an application in
control of electrical distribution grids

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Agenda

- Empowerment
  - Analogon
  - Principles and goal
  - Definition
- Control of electrical distribution grids
  - Voltage control by power factor adaption
  - Limits in the low-voltage grid
  - Application of Empowerment
- Conclusion and perspective

Empowerment

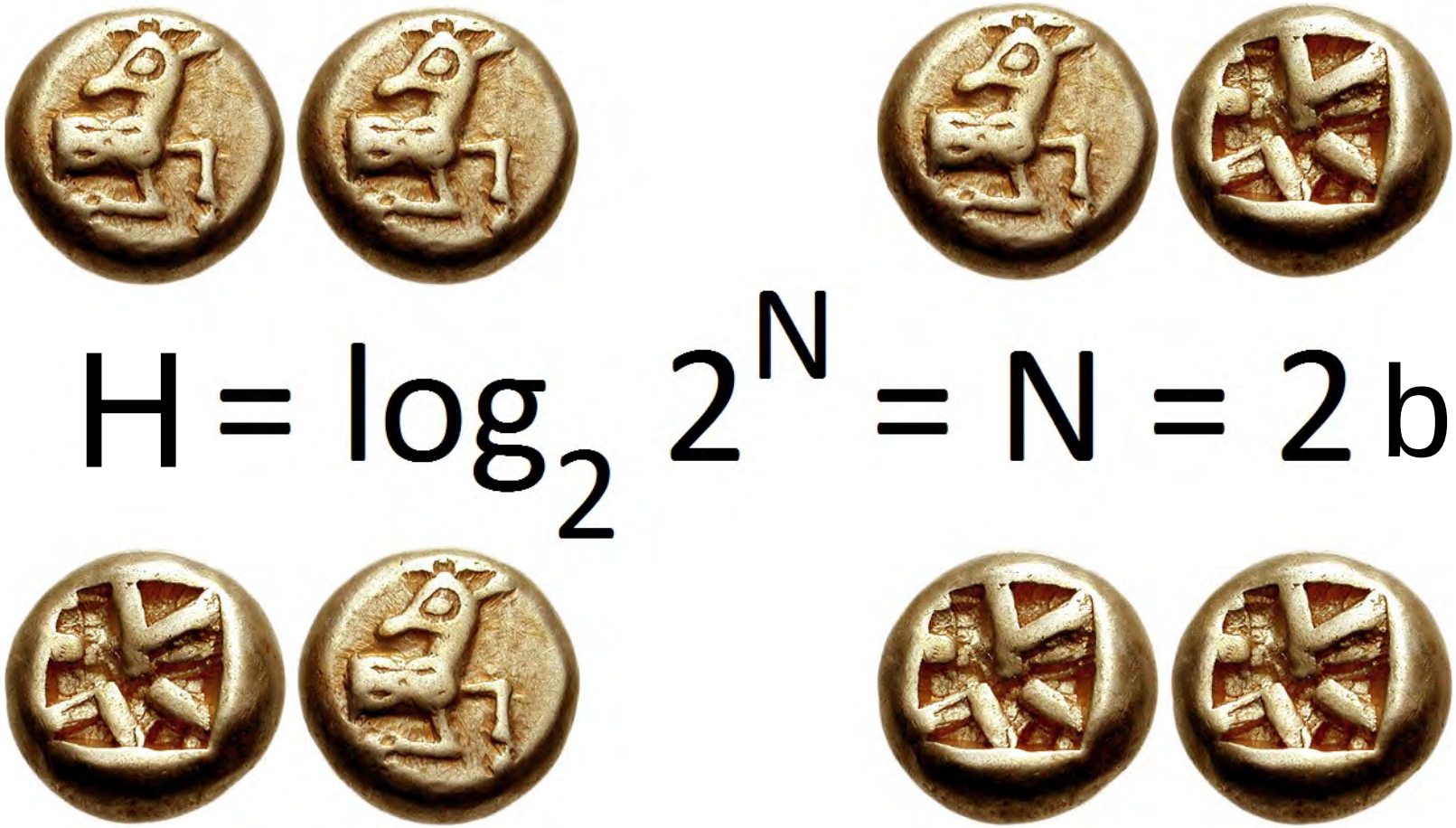
[1]

Principles and goal

- Main Principles [2]:
  - Local
  - Universal
  - Task-independent
- Heuristic:
  'The state of the most perspectives of influence is the best'

- Quantify the amount of influence with the information theoretical entropy

Entropy

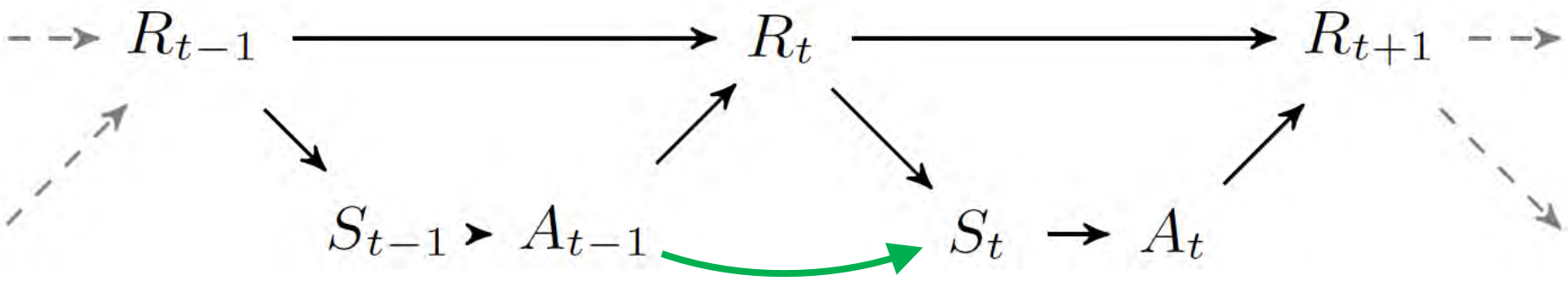


$$H = \log_2 2^N = N = 2 \text{ bits}$$

[3]

Interaction of agent and environment

- The agent performs a perception action loop with
  - Its own actuator A (sender)
  - The environment R (transmitter)
  - Its own sensor S (receiver)



[2]

Mutual information

$$H(S_s) = -\sum_{s' \in S_s} p(s'|s) \log_2 p(s'|s)$$

$$H(S_s|\mathcal{A}_s) = -\sum_{a \in \mathcal{A}_s} p(a) \sum_{s' \in S_s} p(s'|s,a) \log_2 p(s'|s,a)$$

$$I(S_s : \mathcal{A}_s) = H(S_s) - H(S_s|\mathcal{A}_s)$$

Legend of variables:

$I(S_s : \mathcal{A}_s)$	mutual information of the channel between sensor and actuator
$H(S_s)$	entropy of sensor set S_s
$H(S_s\|\mathcal{A}_s)$	conditional entropy of the sensor set S_s given actuator $\mathcal{A}_s$
$\mathcal{A}_s$	discrete random variable modeling selection of action
$p(\vec{a})$	distribution over $\mathcal{A}_s$ (number-of-actions vector)
S_s	discrete random variable modeling occurance of successor state given s
$p(s'\|s)$	distribution over S_s (number-of-sensor-output vector)
$p(s'\|s,a)$	transition probabilities (dynamics of the world)

[2]

Empowerment

$$\mathfrak{E} = C(s) := \max_{p(\vec{a})} I(S_s : \mathcal{A}_s)$$

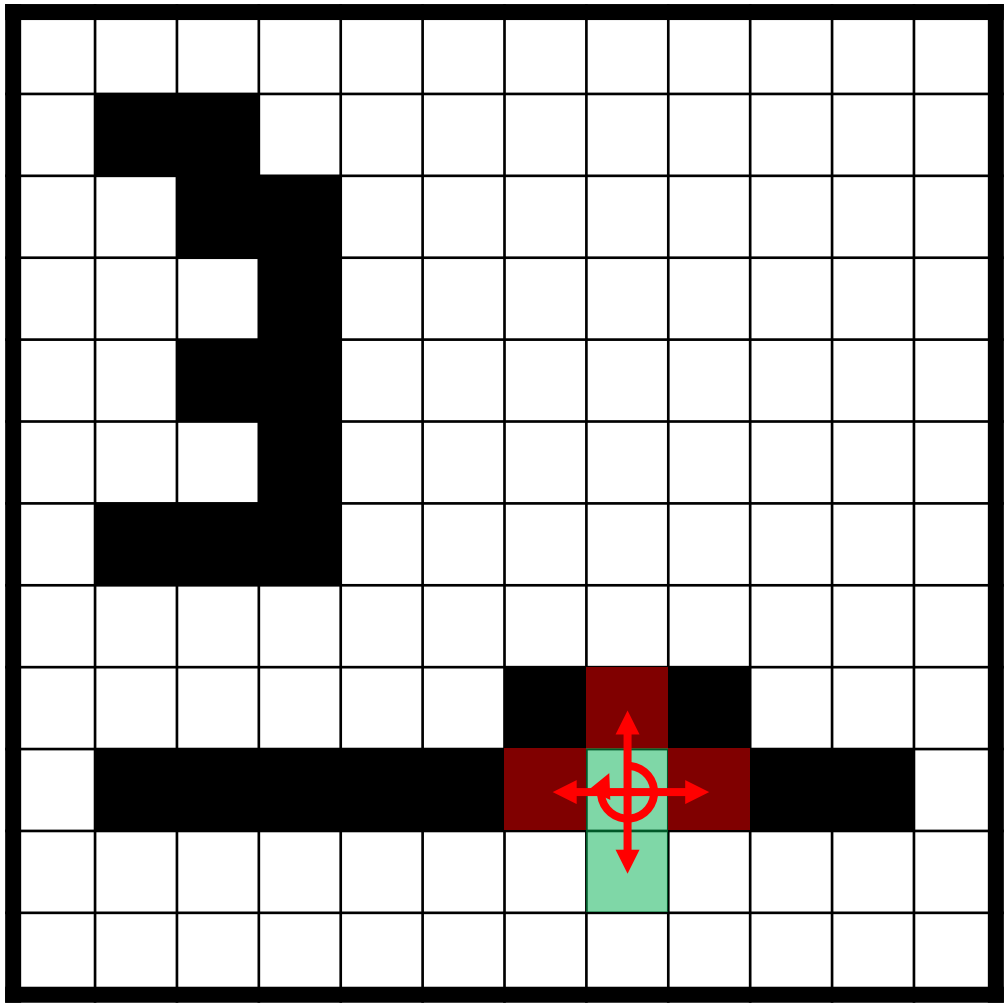
$$\mathfrak{E} = \max_{p(\vec{a})} \sum_{s'} \sum_{a} p(a) p(s'|s,a) \log_2 \left\{ \frac{p(s'|s,a)}{\sum_{a'} p(s'|s,a') p(a')} \right\}$$

Legend of variables:

$\mathfrak{E}$	Empowerment [bits]
$C(s)$	Channel capacity
$I(S_s : \mathcal{A}_s)$	mutual information of the channel between sensor and actuator
$\mathcal{A}_s$	discrete random variable modeling selection of action
$p(\vec{a})$	distribution over $\mathcal{A}_s$ (number-of-actions vector)
S_s	discrete random variable modeling occurance of successor state given s
$p(s'\|s,a)$	transition probabilities (dynamics of the world)

[2]

Grid world example

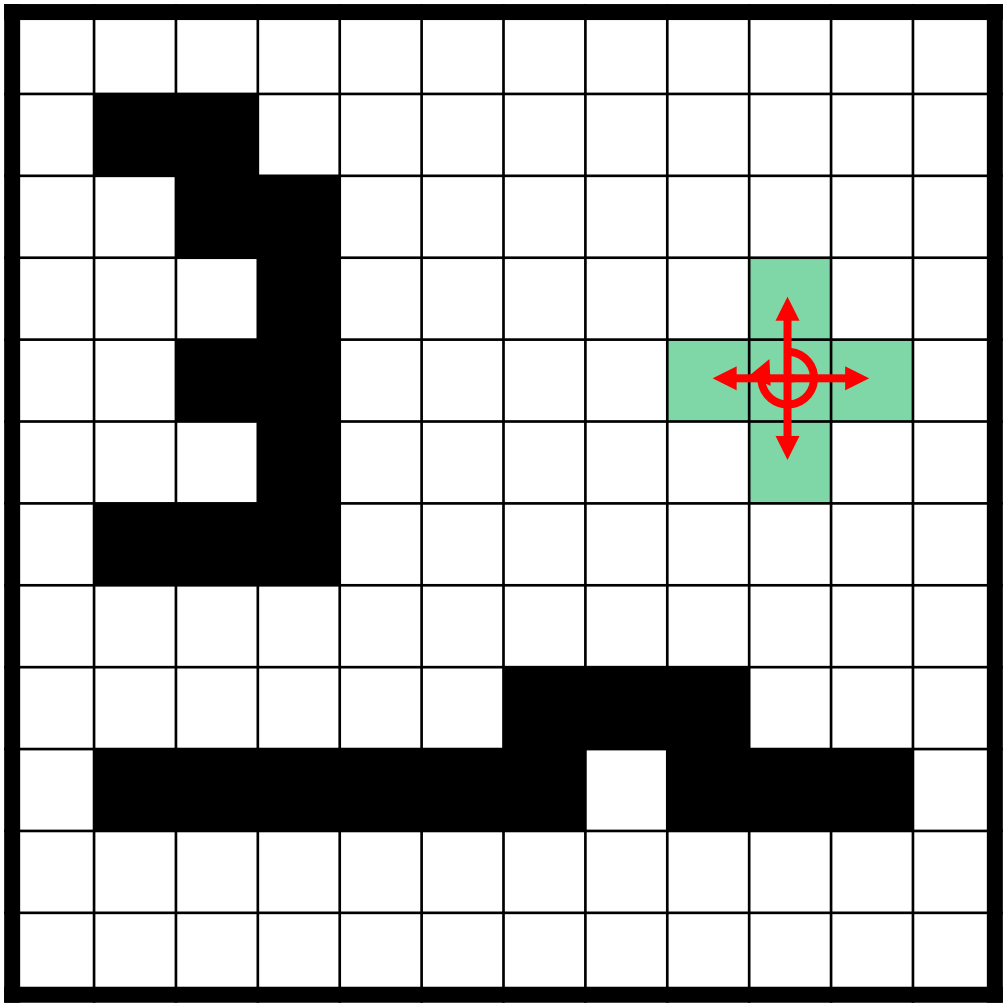


X
N
E
S
W

$$\mathbb{E} = \log_2 2 = 1$$

[4]

Grid world example

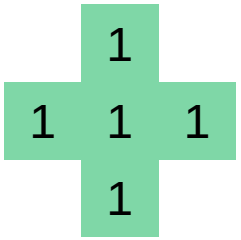
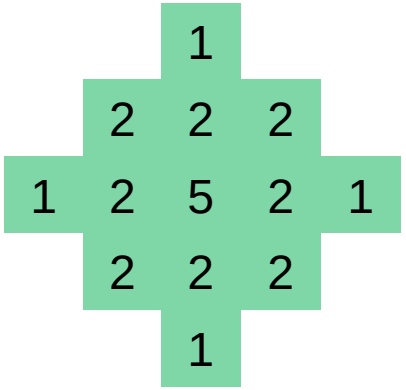
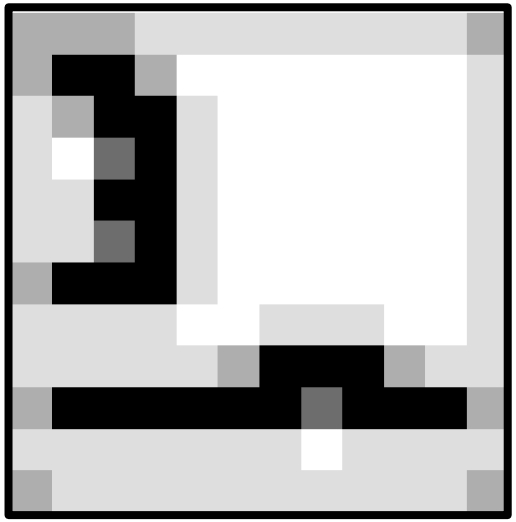
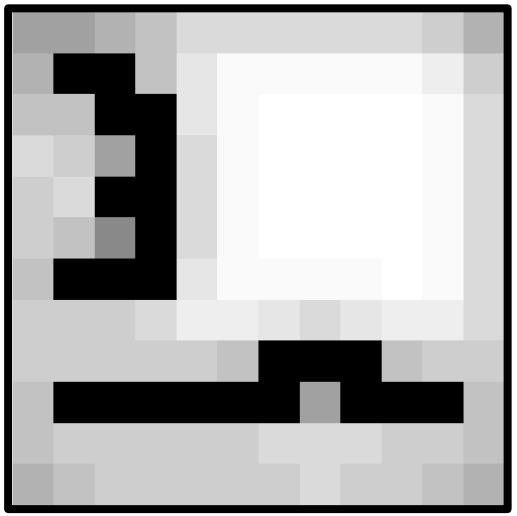


X
N
E
S
W

$$\mathbb{E} = \log_2 5 = 2.32$$

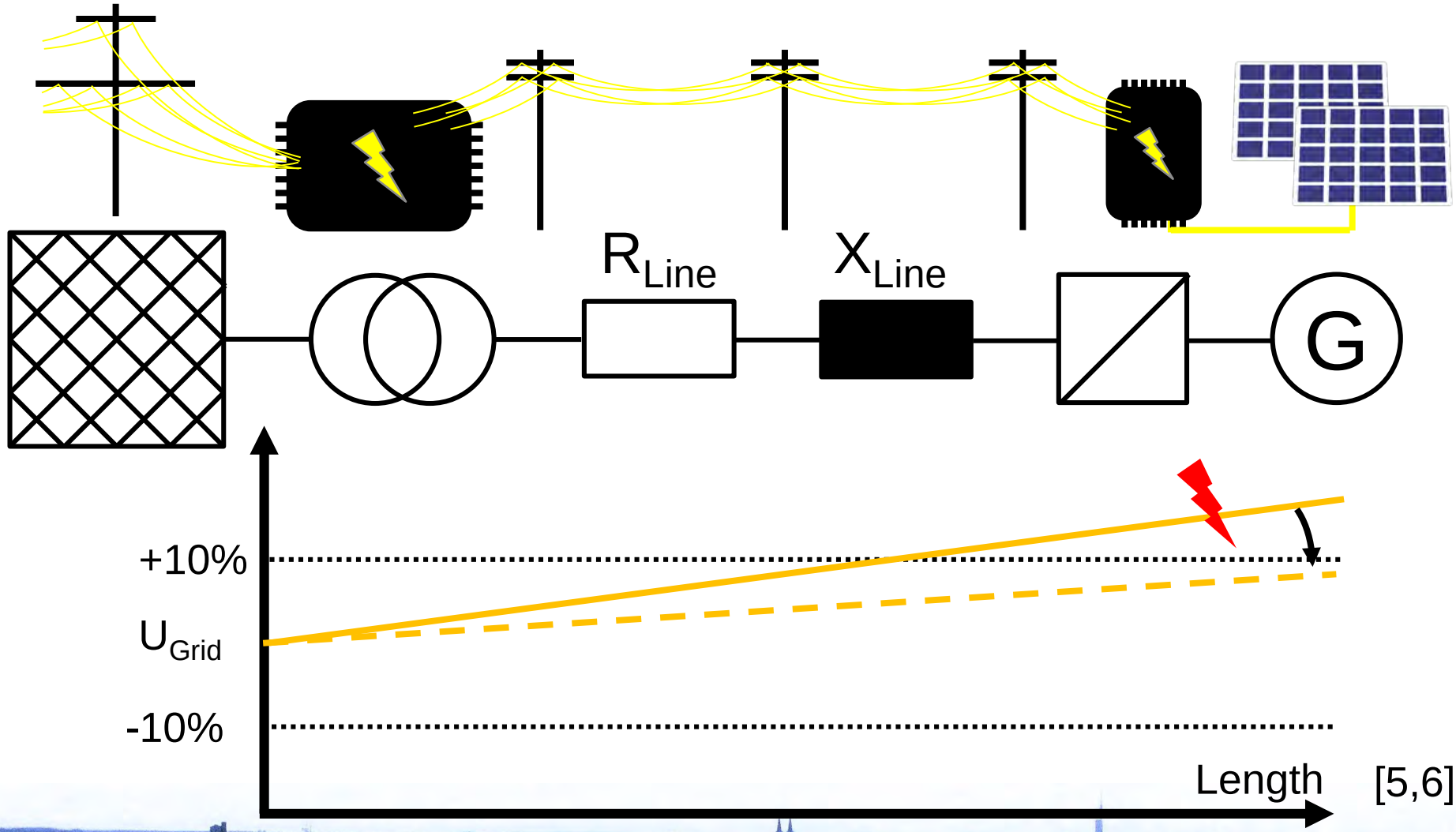
[4]

Application of Empowerment to Gridworld

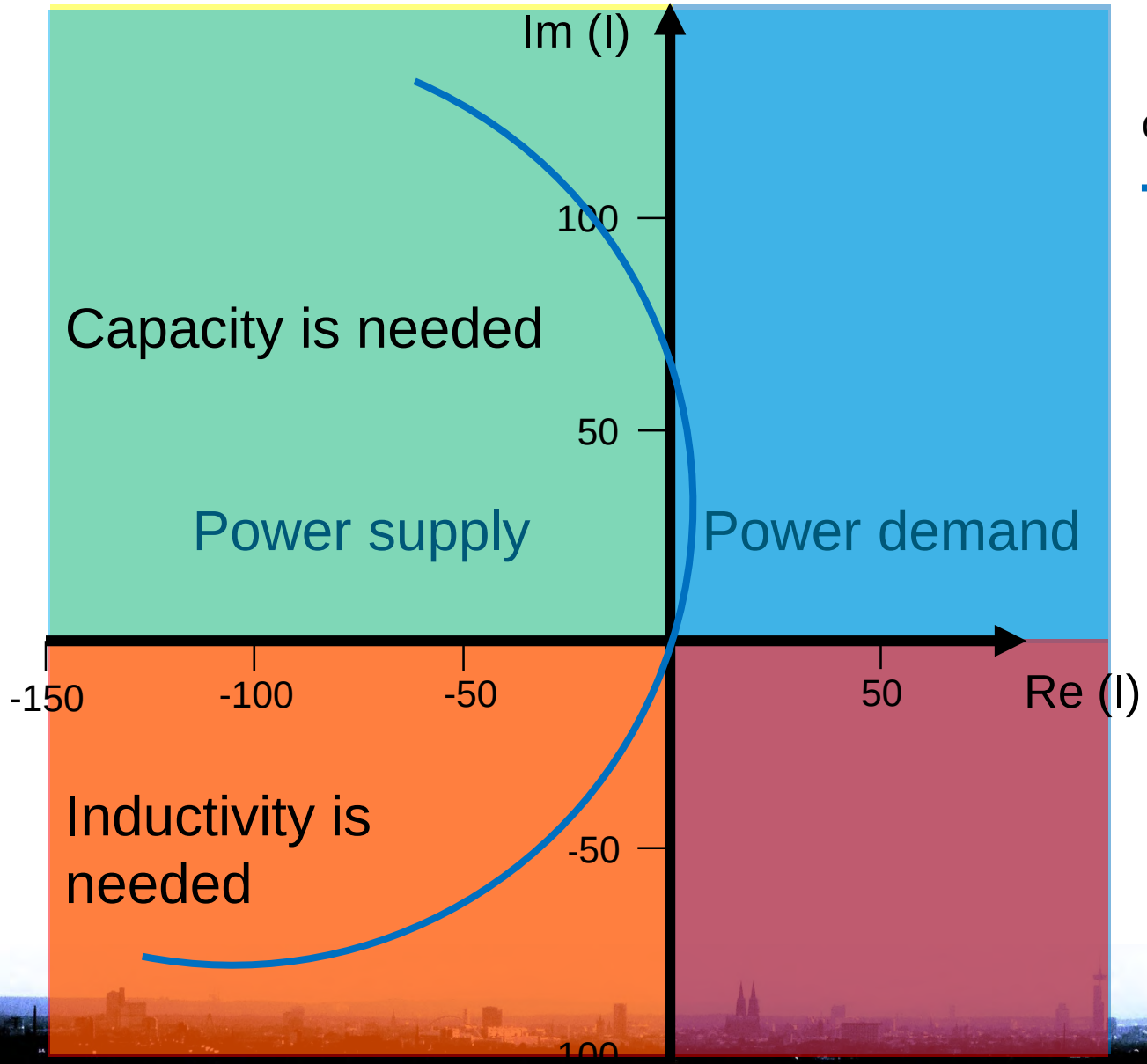
	1-step-$\mathfrak{E}$	2-step-$\mathfrak{E}$
Number of possible paths achieving a particular cell		
Empowerment-map		
[min; max] of $\mathfrak{E}$	[1; 2,32]	[2; 3,70]

[4]

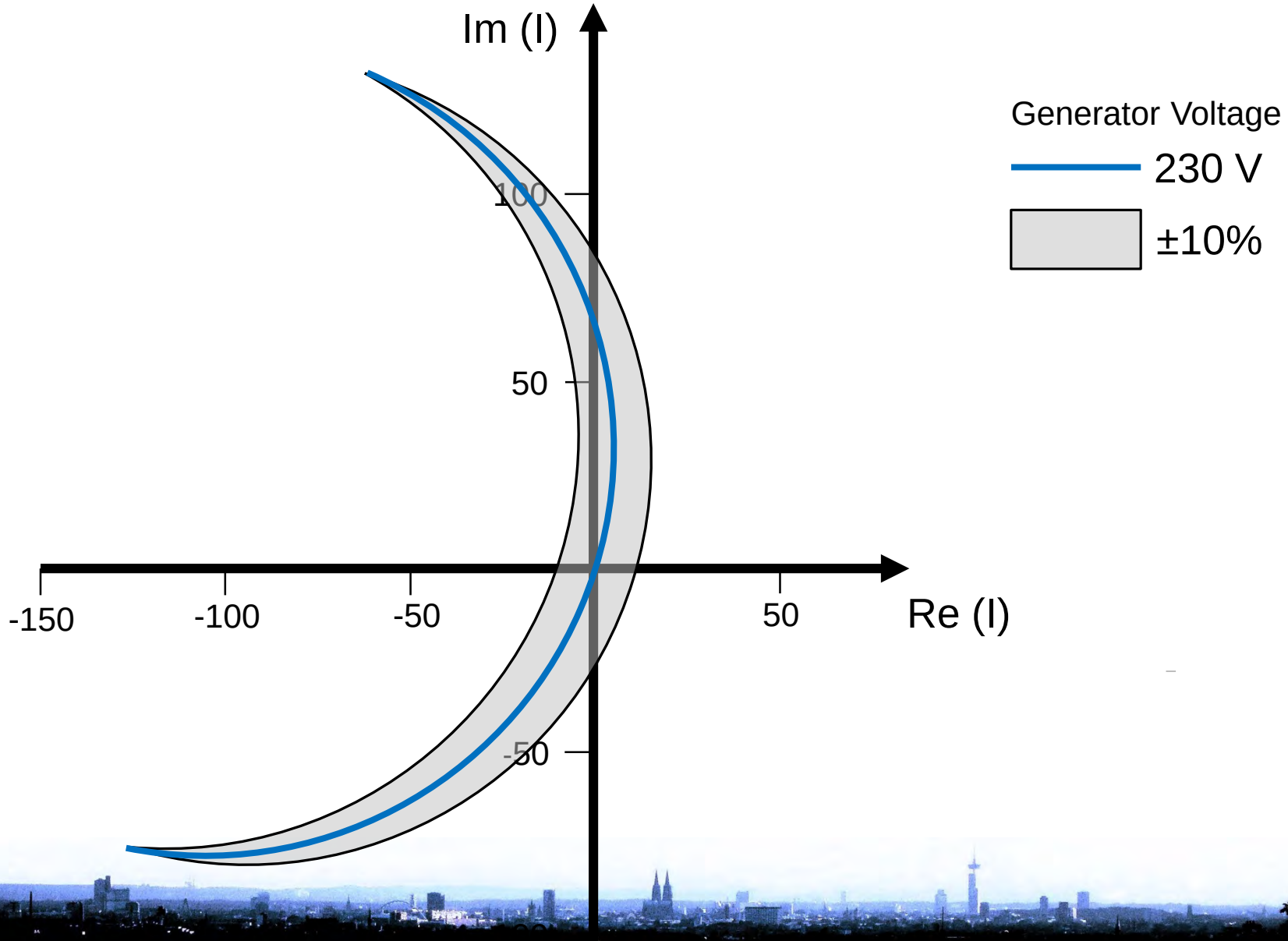
Control of electrical distribution grids



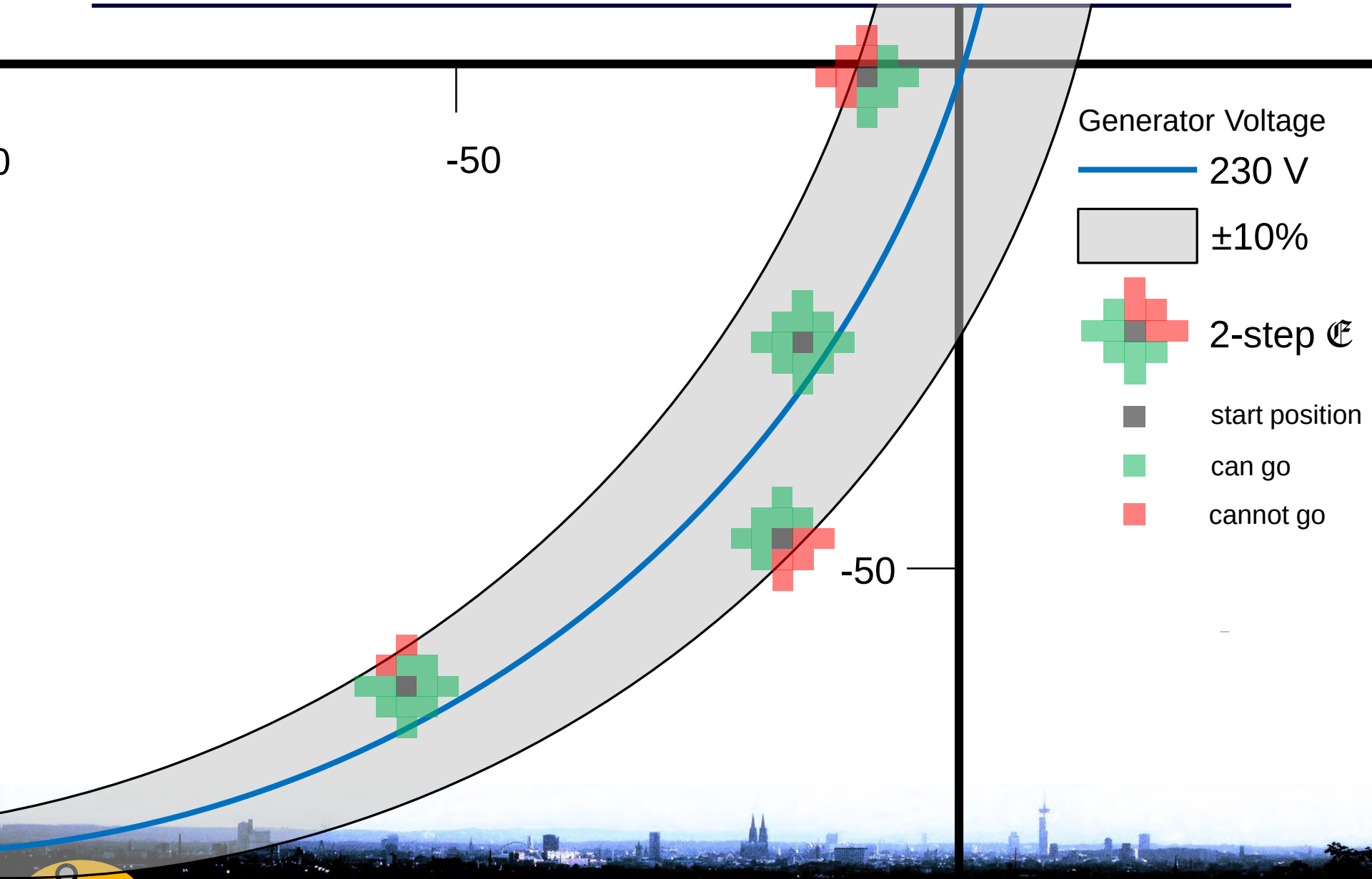
Power factor adaption



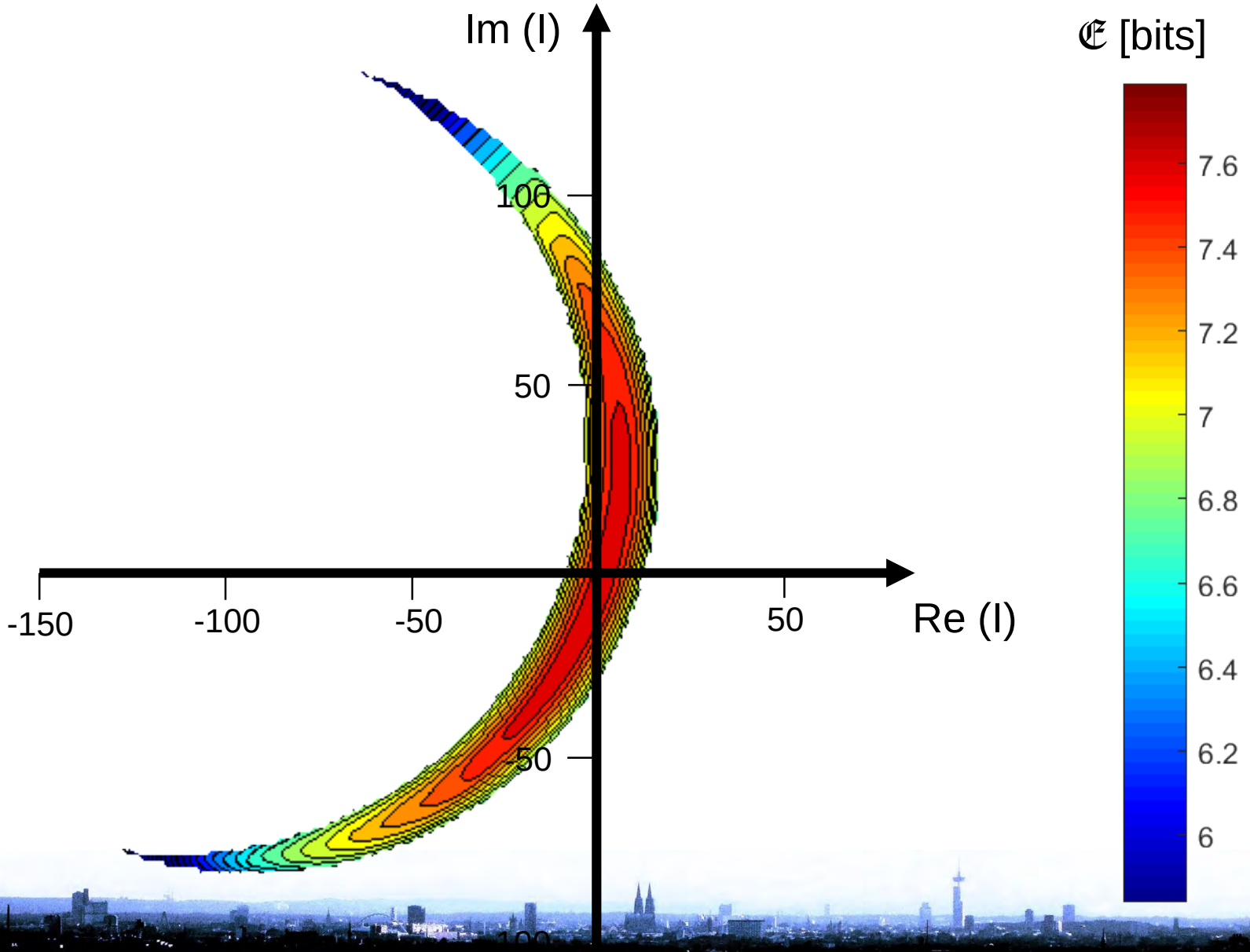
System limits



Application of Empowerment



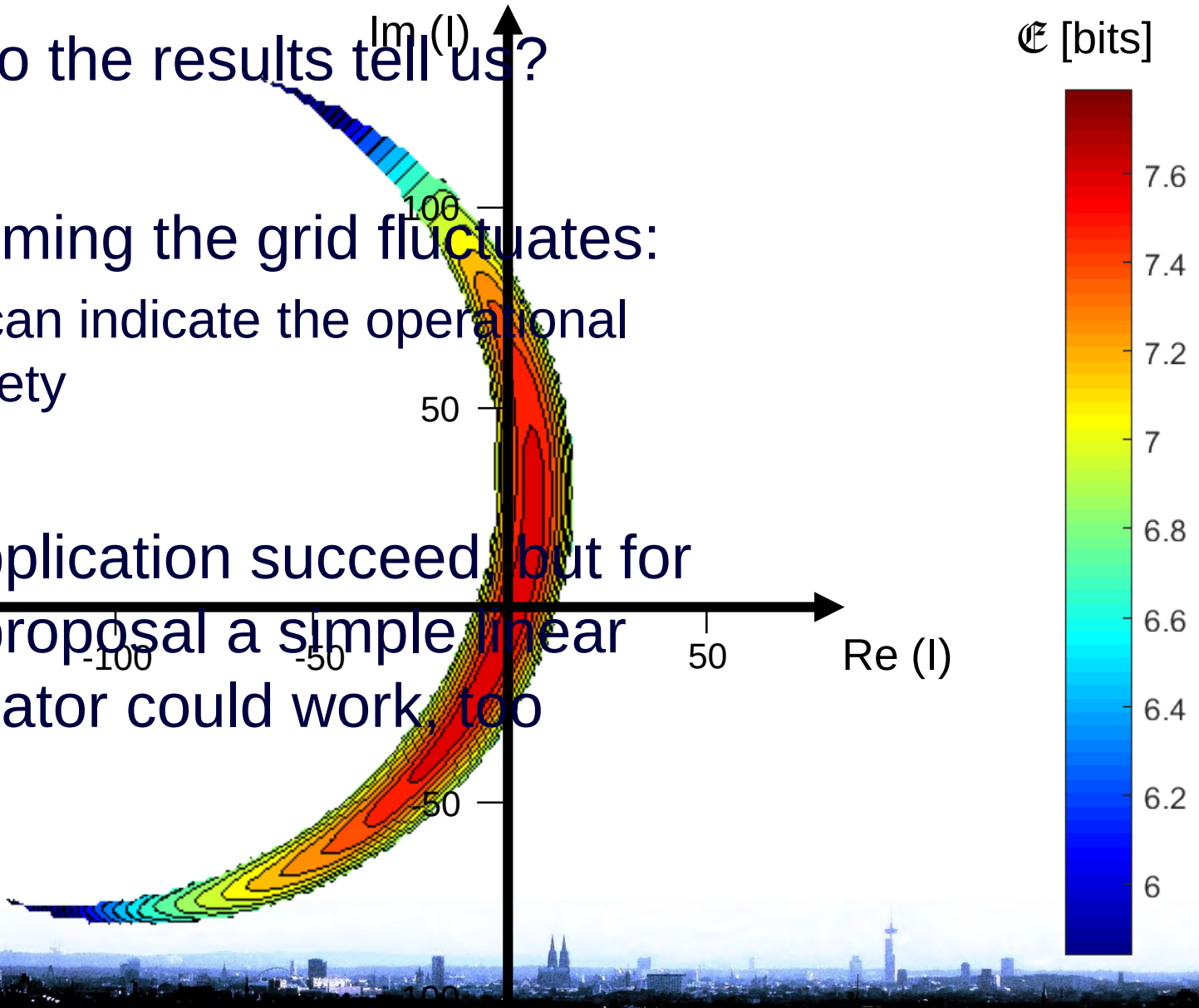
Application of 10-step-Empowerment



Conclusion

What do the results tell us?

- Assuming the grid fluctuates:
  - $\mathfrak{E}$ can indicate the operational safety
- $\mathfrak{E}$-Application succeed, but for our proposal a simple linear regulator could work, too



Perspective

Further research areas and applications:

- Local optimization with blurred limits
  - Probability distribution for Actions of the agent
- Self-organization [7]
  - Smart-Grid-Agents (Generators, storages and adjustable loads): How to implement Empowerment in a dynamic world?
- Optimization of multi-variable Problems
  - Find optimal operation point of coupling of the energy sectors electricity, heat, gas and mobility
- Optimization of problems with competing goals
  - Smart provision of balancing power

Thank you for your attention!

Do you have any more ideas for an application of Empowerment?

References

[1] Wikipedia, “Kaffernbüffel – Fressfeinde und Feindverhalten” [Online] Available: https://upload.wikimedia.org/wikipedia/commons/5/50/Lioness_vs_Cape_Buffalo.jpg [Accessed: 01.06.2016]

[2] C. Salge, G. Glackin, D. Polani, “Empowerment – An introduction”, University of Hertfordshire, 2013

[3] Wikipedia, “Entropy (information theory)” [Online] Available: https://upload.wikimedia.org/wikipedia/commons/d/d4/Entropy_flip_2_coins.jpg [Accessed: 01.06.2016]

[4] A. S. Klyubin, D. Polani, C. L. Nehaniv, “All Else Being Equal Be Empowered”, University of Hertfordshire, 2005

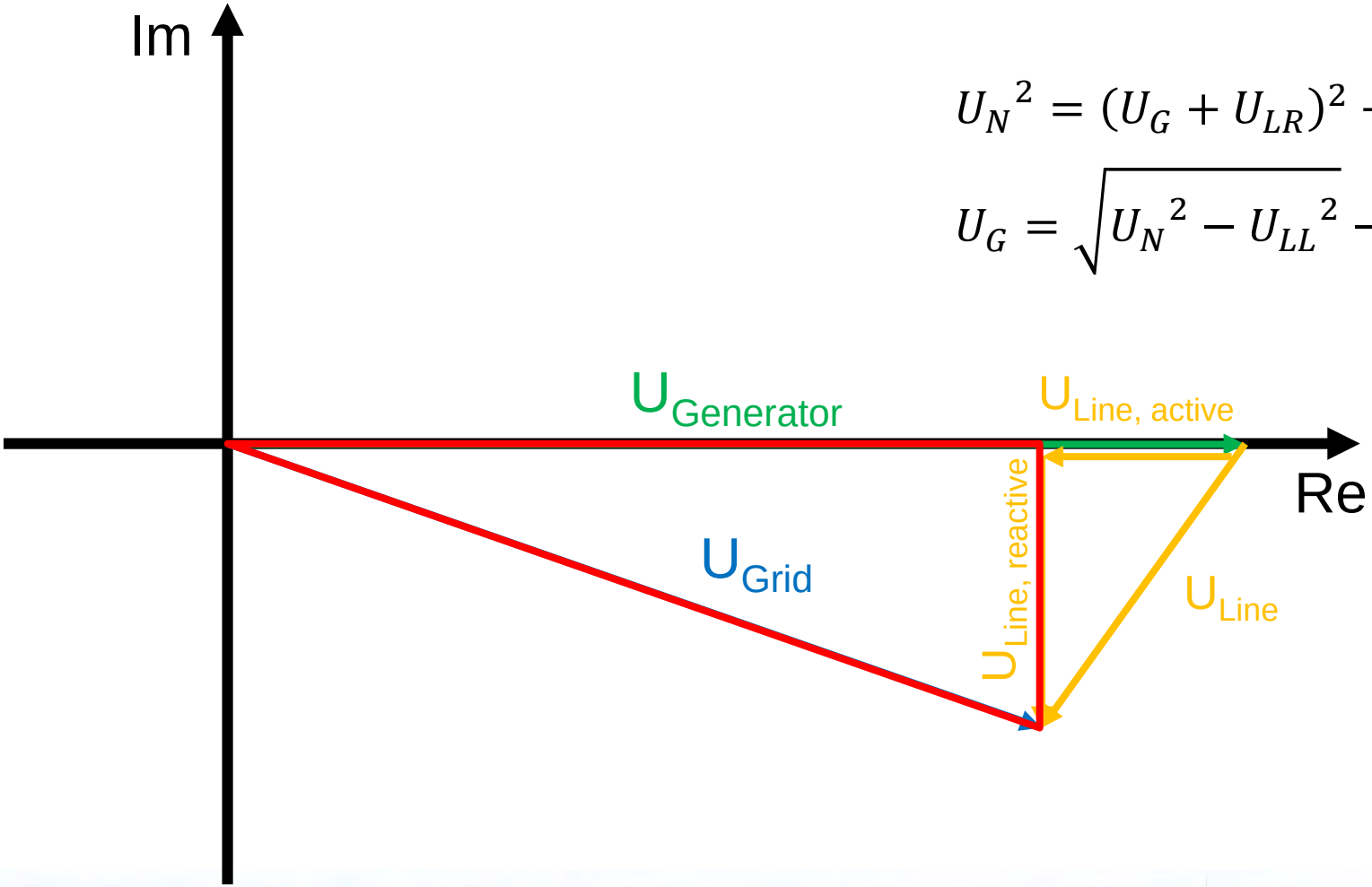
[5] E. Waffenschmidt, “Electric grids - Lecture notes”, 2014

[6] E. Waffenschmidt, “Decentralized structures of electric grids - Lecture notes”, 2015

[7] P. Capdepuy, “Informational principles of Perception-action loops and collective behaviours”, doctoral thesis, University of Hertfordshire, 2010

Annex: Power factor adaption

- Voltages in polar diagram



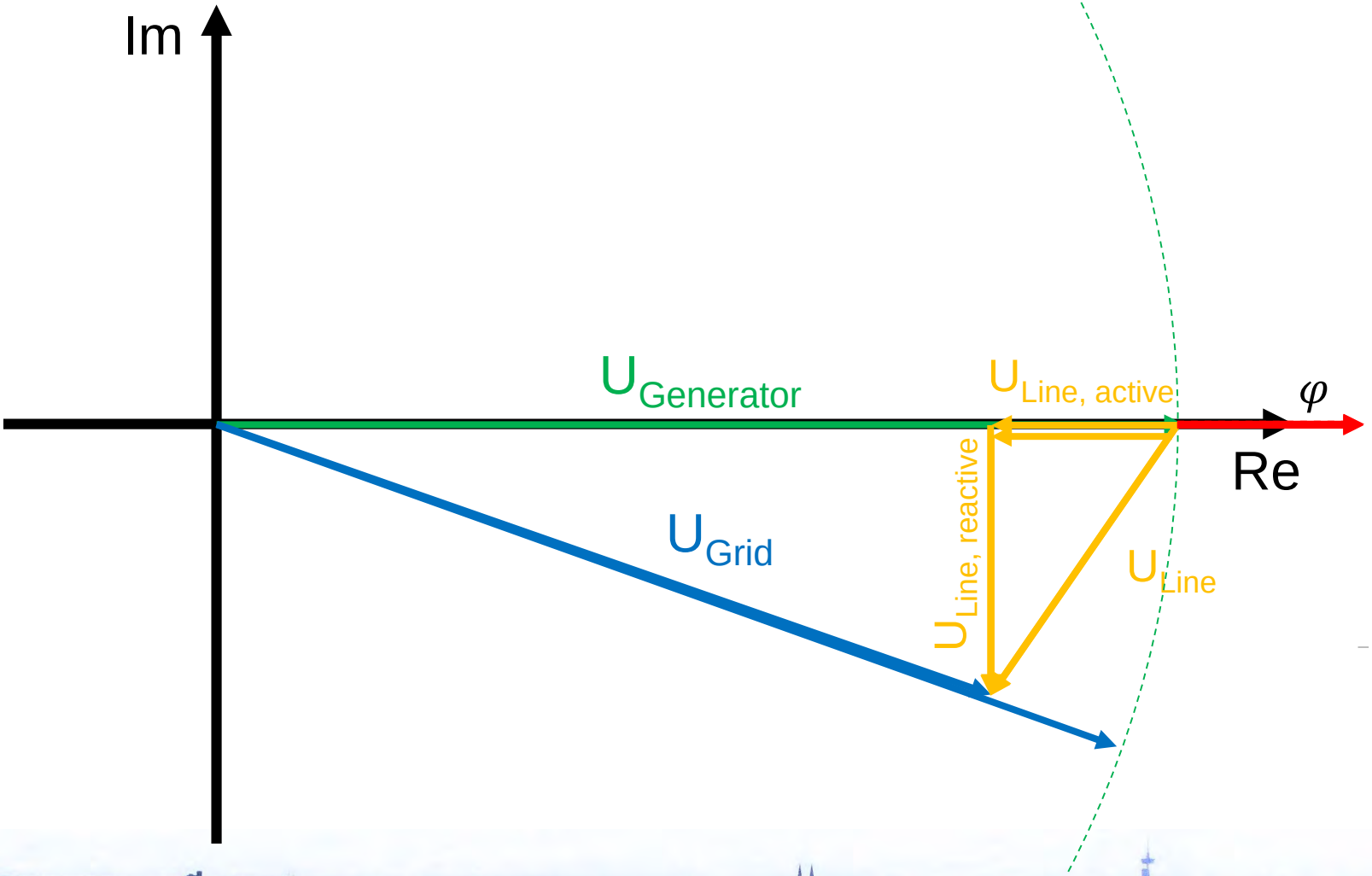
$$U_N{}^2 = (U_G + U_{LR})^2 + U_{LL}{}^2$$

$$U_G = \sqrt{U_N{}^2 - U_{LL}{}^2} - U_{LL}$$

[5]

Annex: Power factor adaption

- Voltages in polar diagram



[5]

Annex: Power factor adaption