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Advanced voltage control in distribution networks

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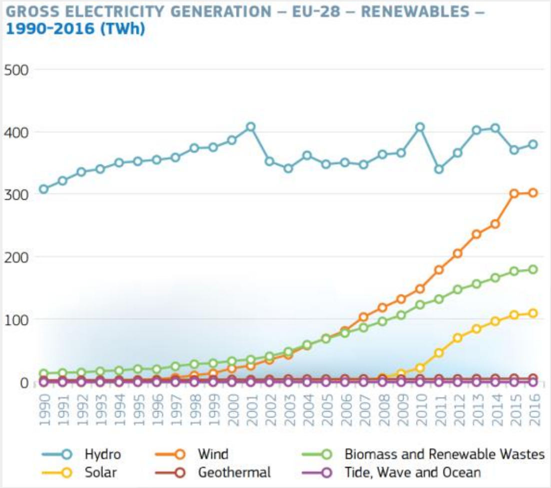
Smagrinet Webinar

Power system challenges

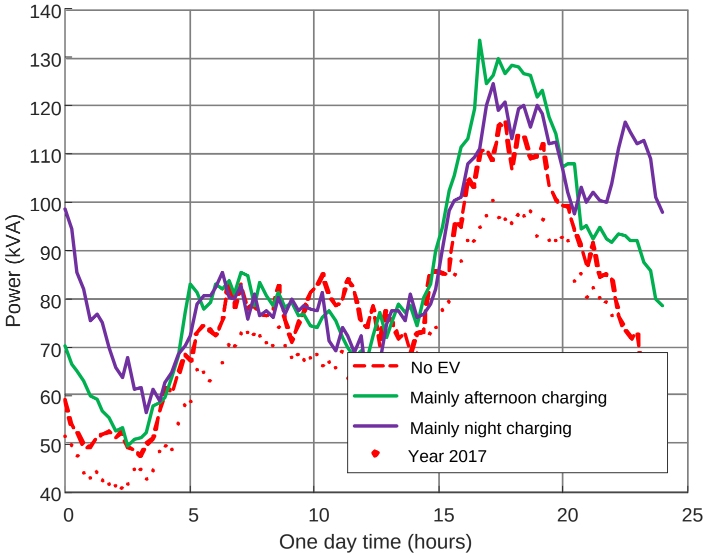
Challenges of the modern power system

- Integration of renewables
  - Impact on distribution network operation
    - **Voltage increase**
  - Increased power fluctuations: higher requirements for ancillary services
  - Impact on electricity prices
    - Lowered profitability of classic power plants
    - Higher prices for domestic customers
    - Lower prices for energy-intensive industry

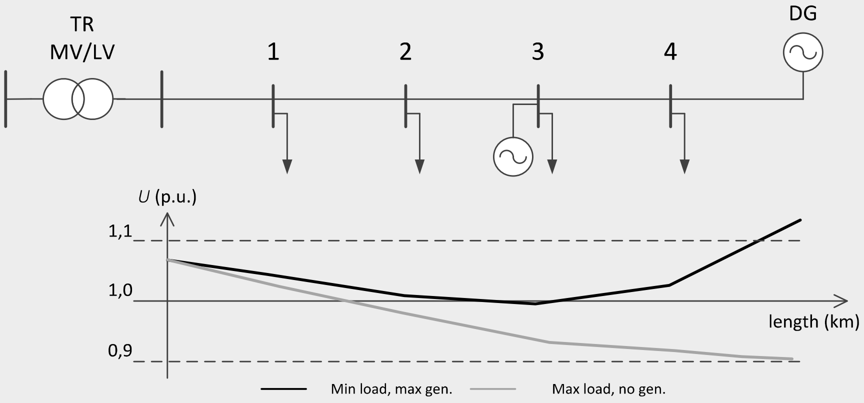


- <u>New loads in the power system</u>
  - Heat pumps (electrification of heating)
  - Electric vehicles (EVs) (electrification of transport)
  - ➢ Transition of heat and transport to the electricity sector
- Why are EVs and heat pumps a challenge?
  - A high share of EVs and heat pumps will have a major impact on the operation of transmission and distribution networks
    - <u>Distribution level</u>
      Overloading, **low voltages**
    - <u>Transmission level</u>
      Variability of power flows, energy requirements

Power-flow through a 160 kVA MV/LV transformer in 2030



- Voltage drop/increase due to loads/distributed generation
    - Simple case with loads and two DG

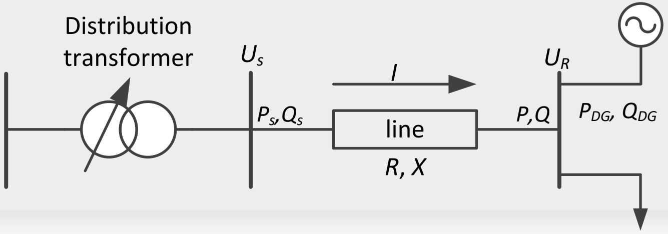


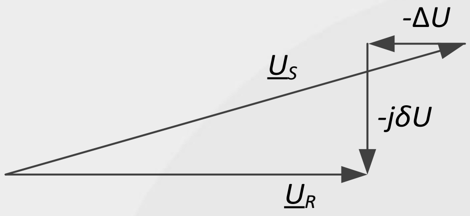
$$\underline{U}_R \cdot \underline{I}^* = P + jQ$$

$$\underline{U}_S = \underline{U}_R + (R + jX) \cdot \underline{I}$$

$$\underline{U}_R = U_R \angle 0^0$$

$$\underline{U}_R = \underline{U}_S - \frac{RP + XQ}{U_R} - j\frac{XP - RQ}{U_R} = \underline{U}_S - \Delta U - j\delta U$$

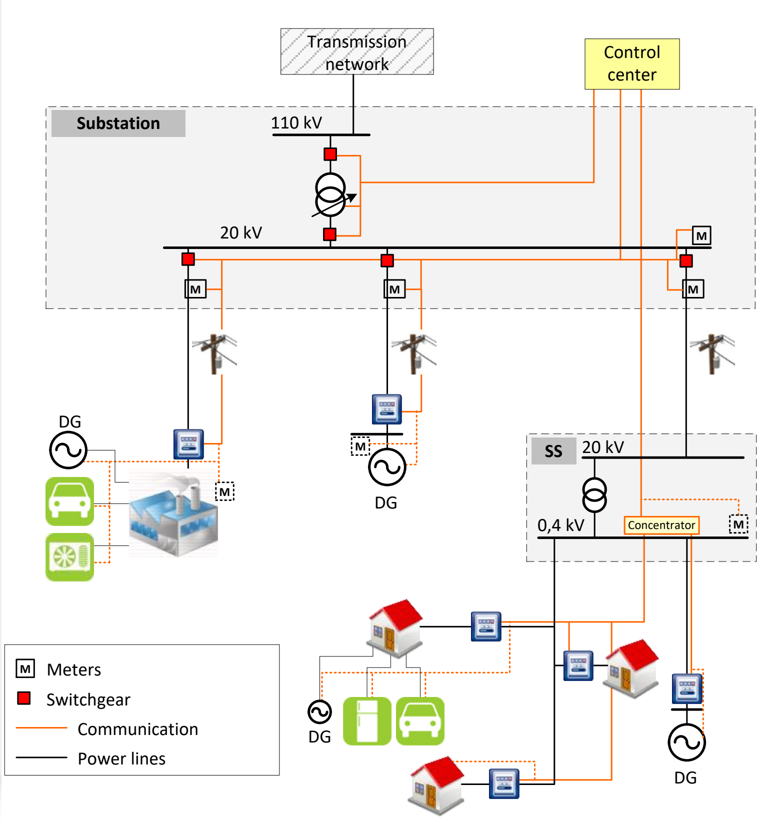




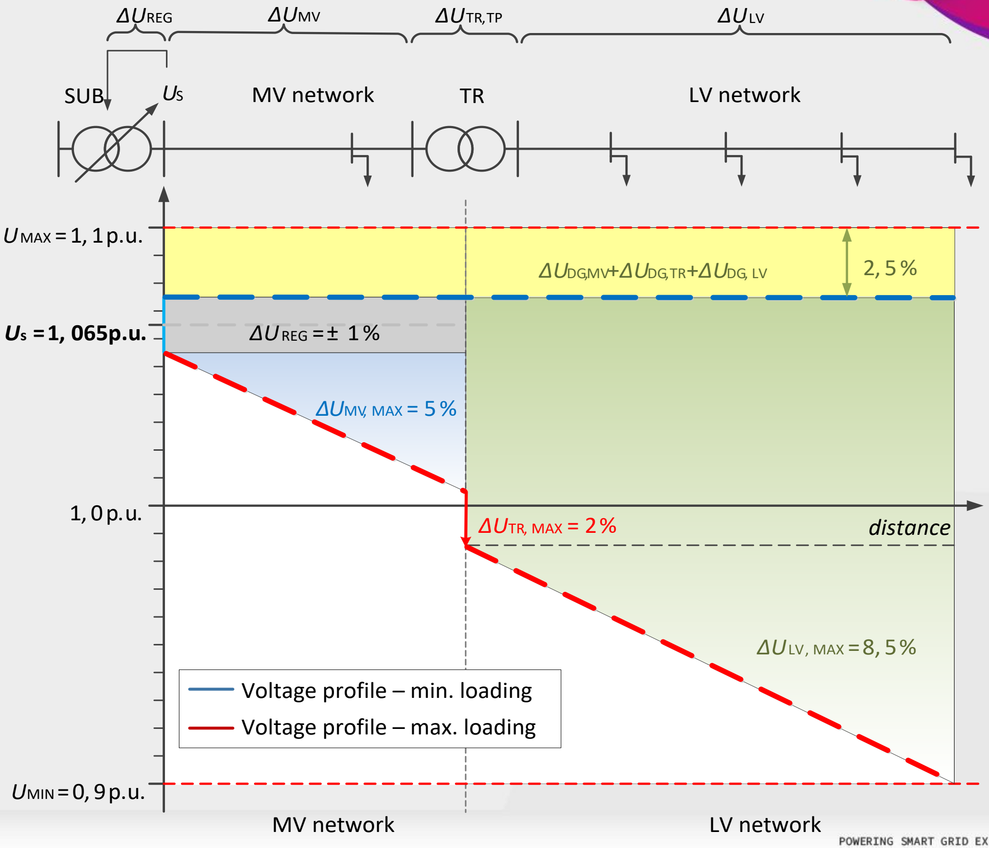
Traditional distribution network voltage control

Distribution network operation

- Distribution network is usually a poorly observable and poorly controllable system
  - Voltage control with an OLTC transformer in the HV/MV substation
  - Voltage control with measurements of one voltage only (substation busbars)
    - Maintaining a reference voltage



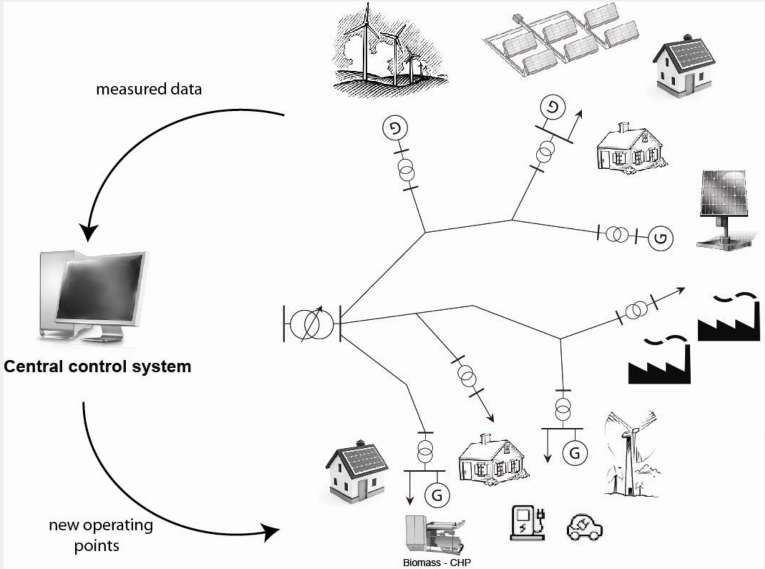
- Traditional distribution network planning
  - Voltage band allocation



Advanced distribution network voltage control

Advanced voltage control

- Advanced voltage control with the OLTC transformer in the HV/MV substation
  - Voltage control with measurements in multiple network points and SE
- Voltage control with an OLTC transformer in the MV/LV secondary substation
- Voltage control with DG
  - *Q=f(U)* control
- Voltage control as a service provided by customers
  - Demand response (adjusting consumption according to network conditions)



- Coordinated voltage control - example
  - OLTC voltage setpoint and DG reactive power setpoints sent by the central voltage control unit (CVCU)
  - Optimisation problem

$$\min_{\Delta Q} \sum_{i=1}^{n} (Q_i + \Delta Q_i)^2$$

minimise the amount of reactive power which must be injected

$$|Q_i + \Delta Q_i| \leq P_i \tan(\arccos(PF_{min}))$$

DG operational constraints – power factor

$$|Q_i + \Delta Q_i| \leq \sqrt{S_n^2 - P_i^2}$$

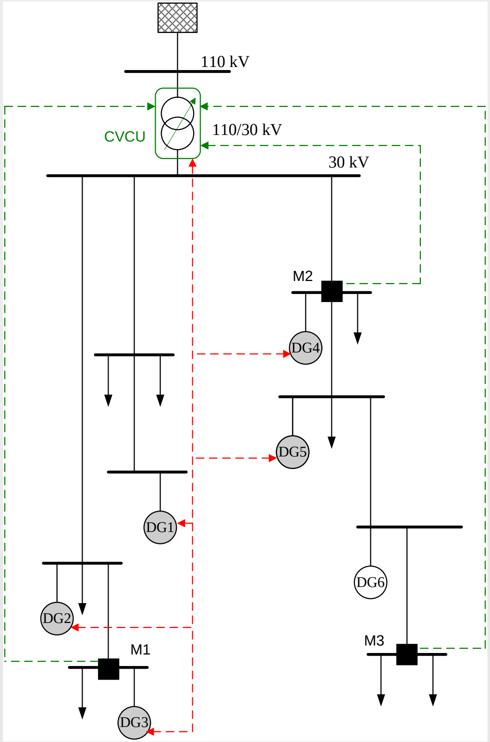
DG operational constraints – apparent power

$$\max(U_j + A_Q \Delta Q_i) - \min(U_j + A_Q \Delta Q_i) \leq EVB$$

Linearized network model – sensitivity matrix

EVB – available voltage band

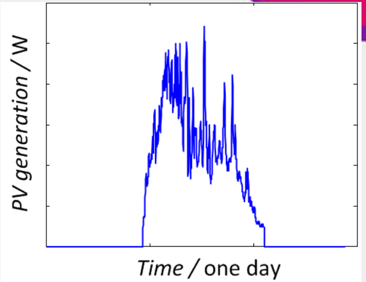
$$max\left(\begin{matrix} U_1 \\ U_n \end{matrix} + \begin{bmatrix} a_{Q|1,1} & \cdots & a_{Q|1,m} \\ \vdots & \ddots & \vdots \\ a_{Q|n,1} & \cdots & a_{Q|1,1} \end{bmatrix} \times \begin{matrix} \Delta Q_1 \\ \Delta Q_n \end{matrix}\right) - min\left(\begin{matrix} U_1 \\ U_n \end{matrix} + \begin{bmatrix} a_{Q|1,1} & \cdots & a_{Q|1,m} \\ \vdots & \ddots & \vdots \\ a_{Q|n,1} & \cdots & a_{Q|1,1} \end{bmatrix} \times \begin{matrix} \Delta Q_1 \\ \Delta Q_n \end{matrix}\right) \leq EVB$$

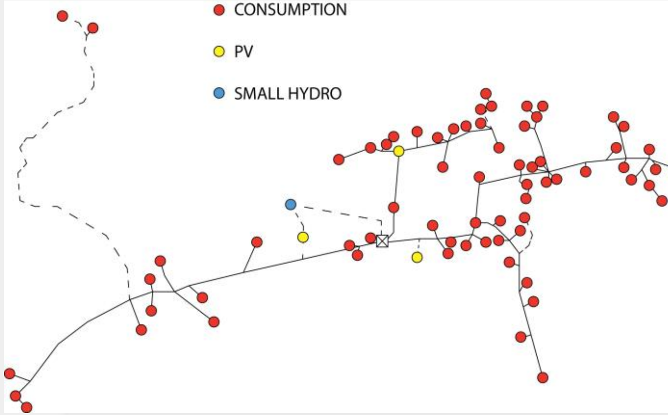


Stochastic approach to power system planning

Modelling of electric power systems for network planning

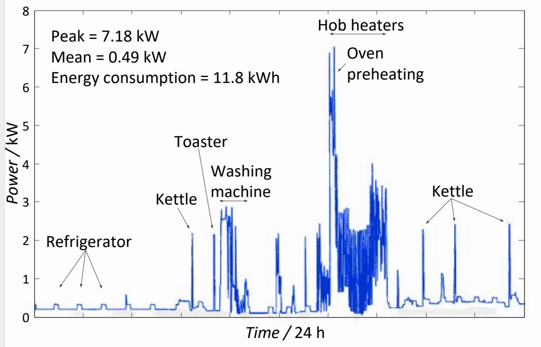
- Network planning: based on the assessment of future operating conditions in a network
  - ➢ Goal: determine a technical and economical optimal network development that will provide the required power quality
- Challenges
  - High variability of distribution network loads
  - High variability of DG
  - Unknown location of future DG
  - EVs: unknown location, power dependant on user behaviour (daily driven distances, plug-in time…)
- Approach
  - Traditional: worst case scenarios
  - Advanced: stochastic modelling approach



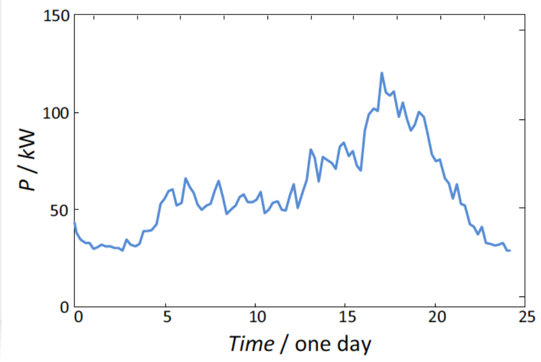


LV distribution network

- High variability of distribution network load

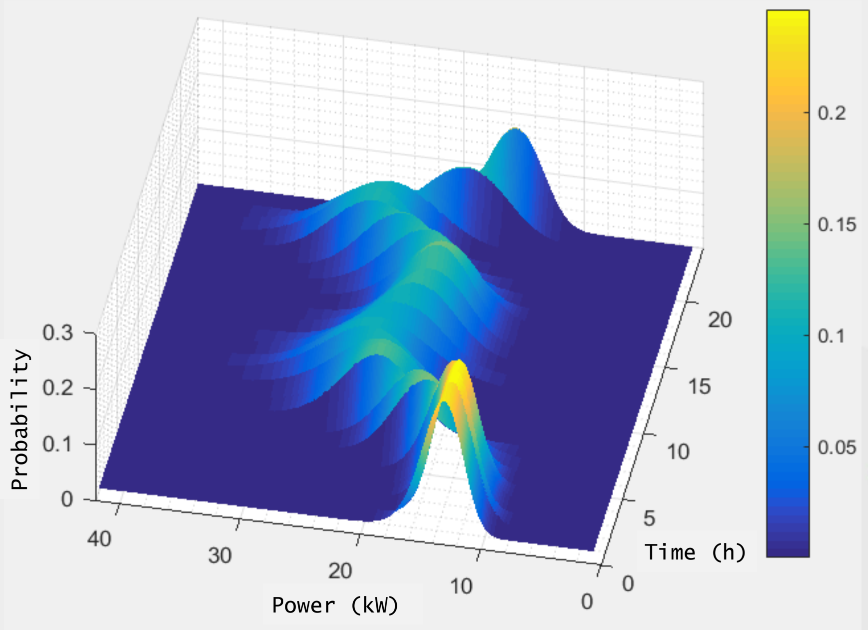


Load diagram of one household

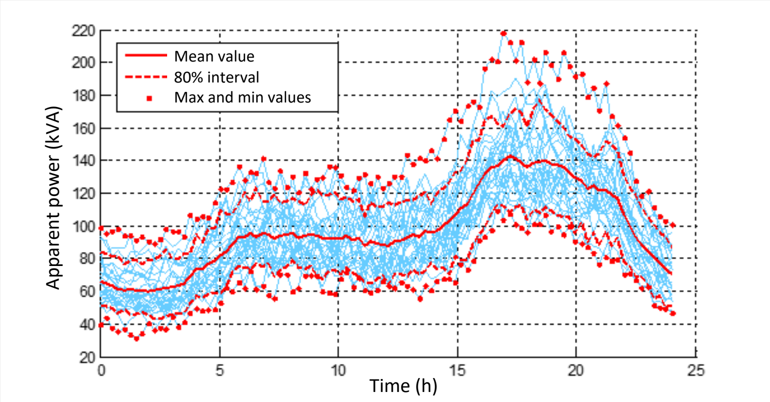


Cumulative load diagram of 84 households

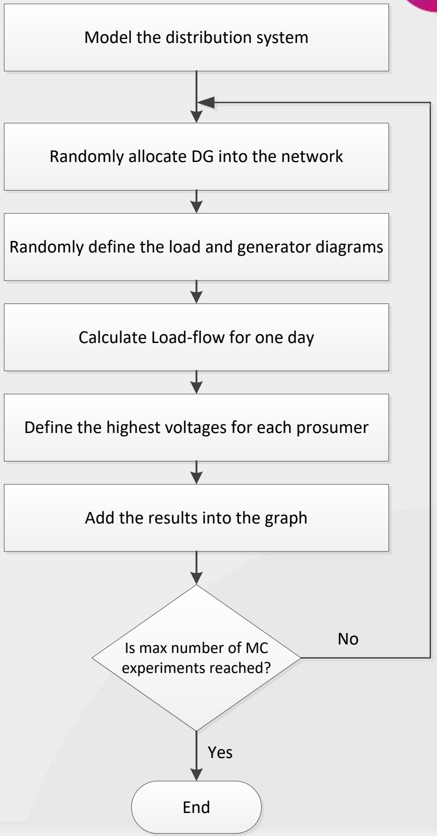
Probability distribution of secondary substation power (weekday, summer)



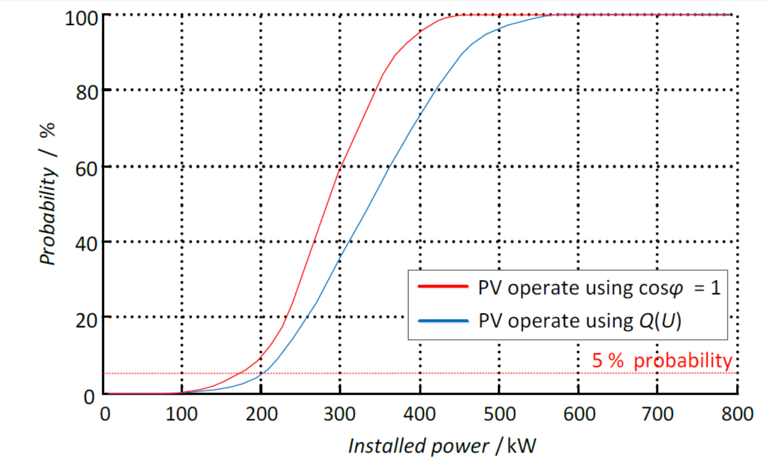
- Modelling
  - Stochastic approach: includes the variability of loads, DG, EV and the location of DG and EV
    - Monte-Carlo simulations
  - Results: probability distribution for a certain variable (U, P…)



Power flow through a transformer for one day



- Results: comparison of probability curves for U>1.10 pu due to DG integration
  - case of DG operation with cosφ =1
  - case of DG operation with a Q(U) characteristic



Overall results

Action / operation mode	Max. amount of DG in the network at the 5 % acceptable risk / kW
Classic (conservative) network planning (DG → max. & P_{LOAD}=0)	115
Probabilistic network planning, PV operate with cosφ = 1	170
Probabilistic network planning, PV operate by using Q(U) characteristics	205

Conclusions

- The power system and especially distribution networks are facing big challenges
  - Renewable sources
  - Electrification of heating
  - Electrification of transport
  - ➢ Big impact on network operation on all voltage levels
- Solutions for adequate voltage profiles
  - Network reinforcement
  - Advanced voltage control
    - better network observability (measurements)
    - better network controllability (controllable elements)

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