Voltage control in distribution networks with windpower

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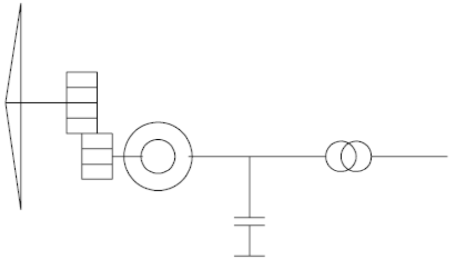
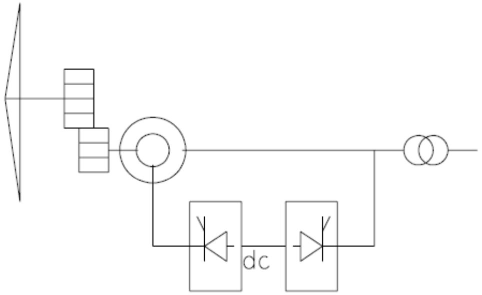
Contents

Wind turbine generator technologies

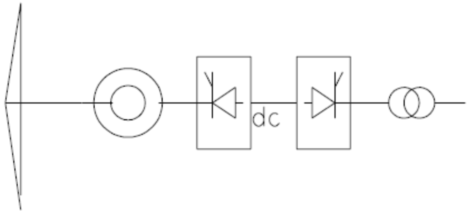
- Induction generator



- Doubly-fed induction generator



- Full-scale converter

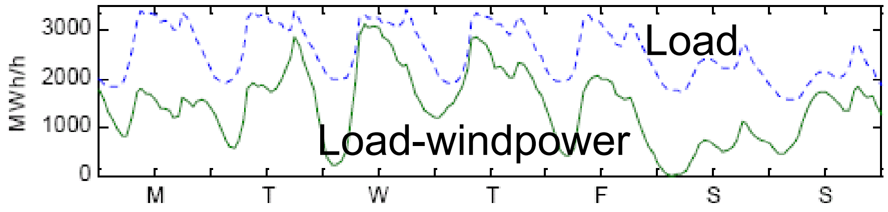


Local level impact of windpower

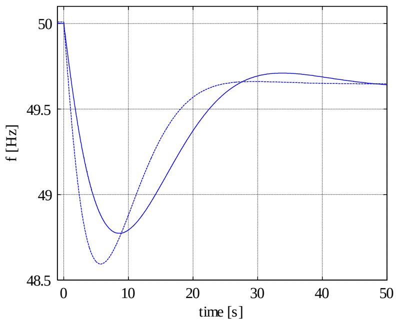
- Risk of island operation at distribution level
    - Anti-island protection
- Power quality
    - Harmonics, voltage dips
- New fault current situation
    - Fault current contribution
- New power flow situation (Ingmar Leiße)
    - Overvoltage may limit connected capacity
    - Losses

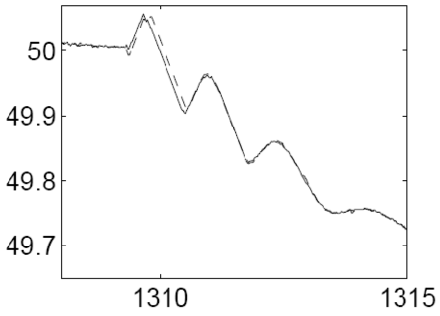
System level impact of windpower

- Variable generation
  - Balancing
- Non-synchronous generators displace synchronous generators



  - Reduced inertia →
    (Johan Björnstedt)

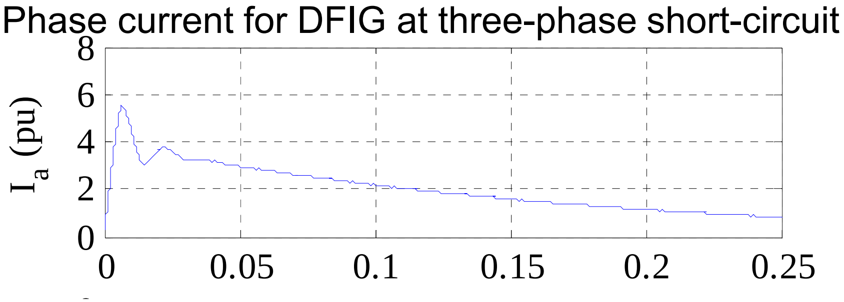




Fault behavior of windpower

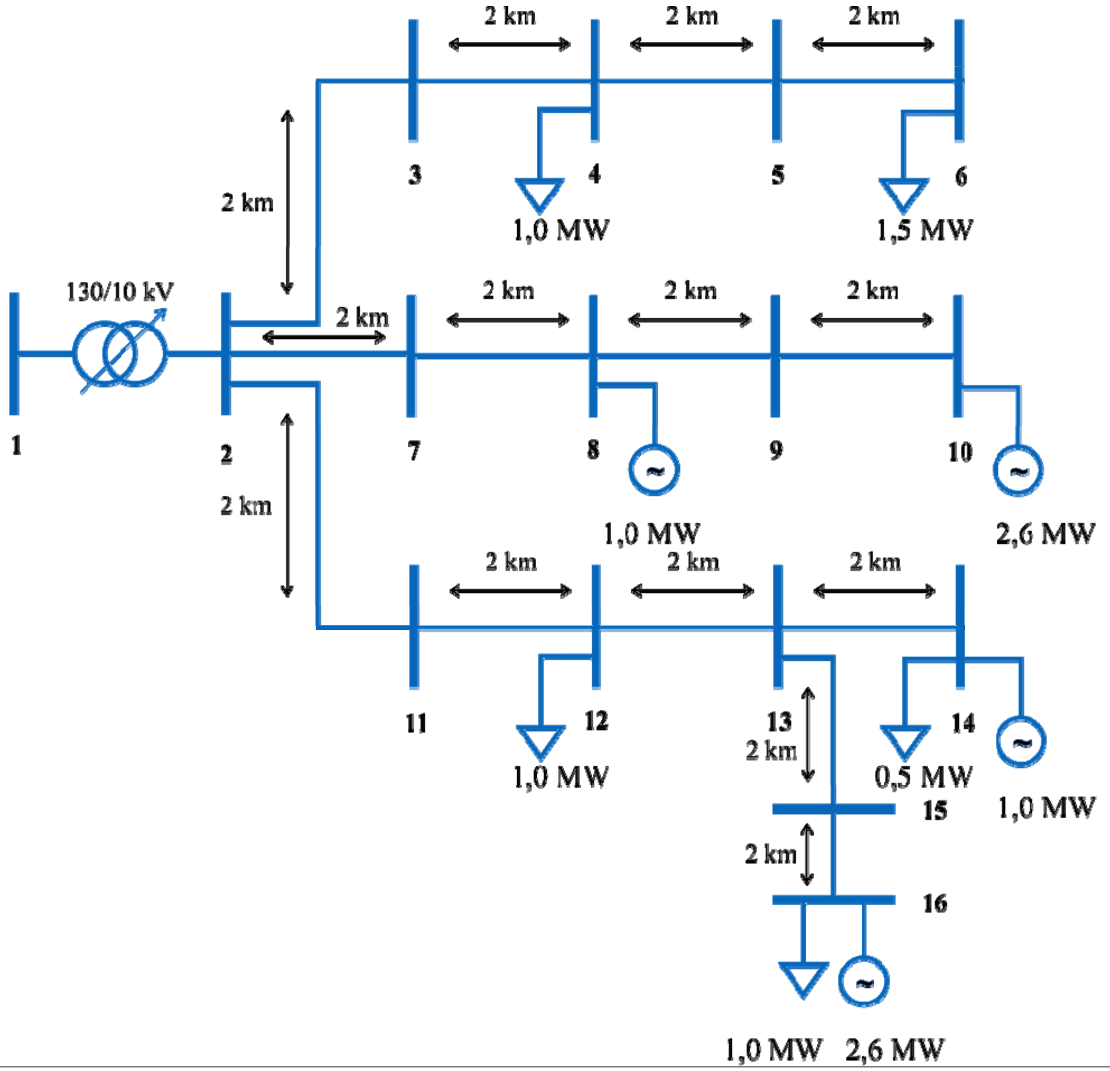
- SG instability related to critical clearing angle
- Induction generator instability related to critical clearing speed
  - Notion of ”Rotor speed stability” proposed

- Calculation of fault currents from DFIG (Francesco Sulla)



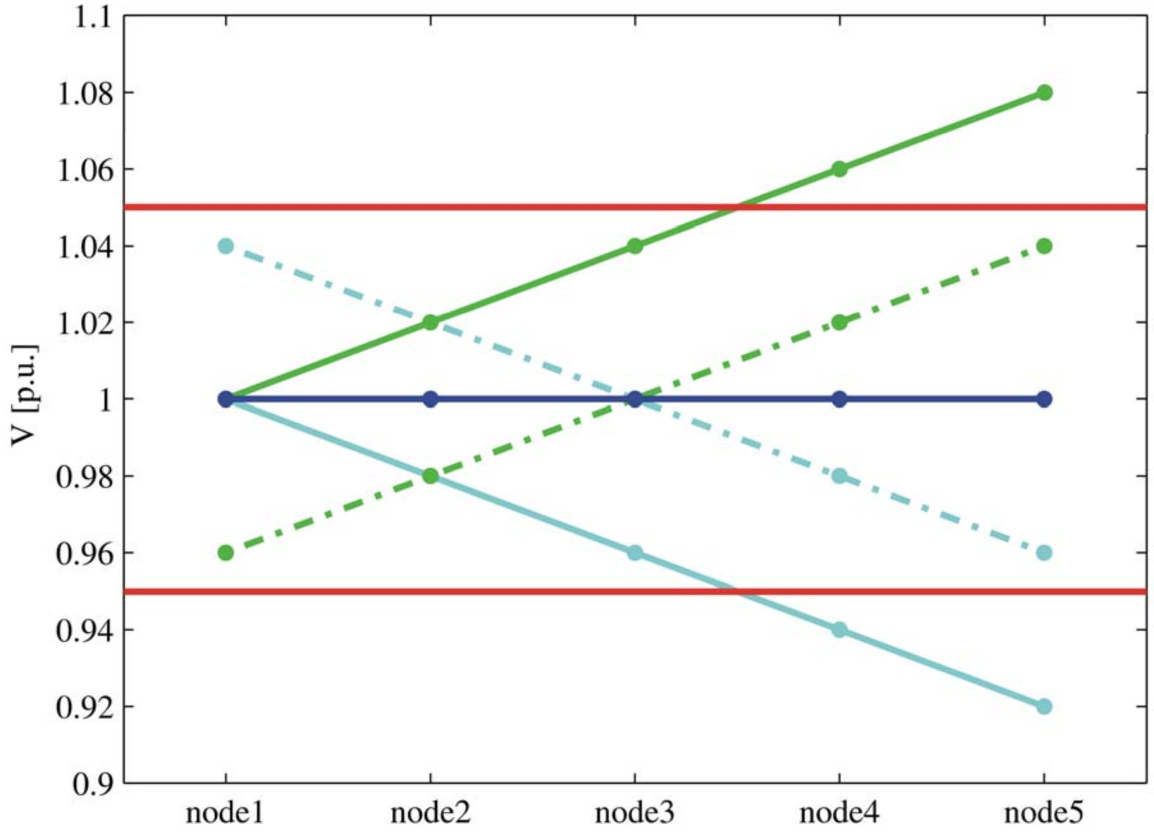
(O. Samuelsson and S. Lindahl. ”On Speed Stability,” IEEE Transactions of Power Systems, Vol. 20, No. 2, pp 1179-1180, 2005)

Voltage: Generic network with tap changer



- 130/10 kV substation with OLTC
- 3 feeders
- 16 nodes
- Load: 5 MW
- Generation: 7.2 MW
- Length: 28 km

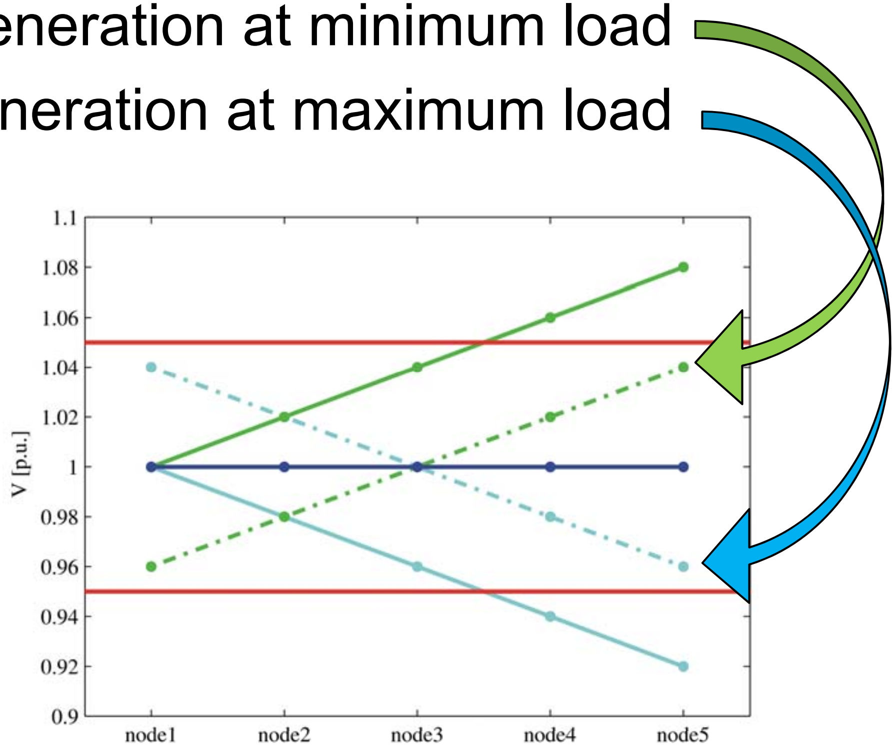
Voltage profile along a feeder



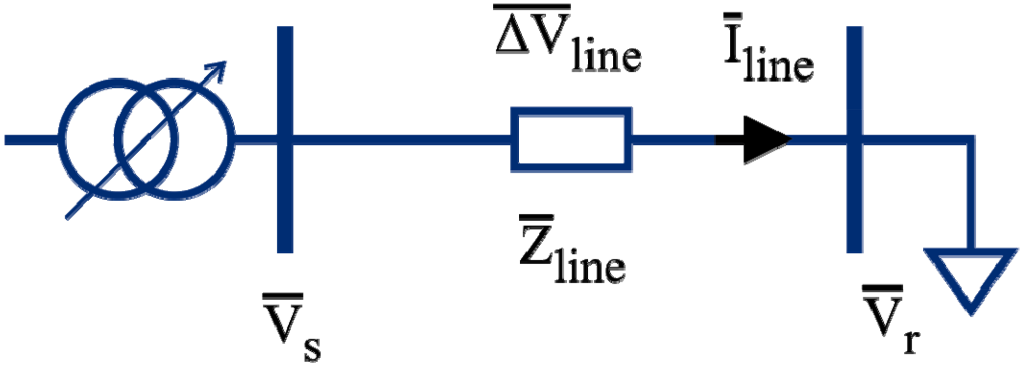
Voltage limits
Load only
Generation only
Load and generation

Voltage-constrained windpower capacity

- Worst cases with tap changer control
  - Maximum generation at minimum load
  - Minimum generation at maximum load



Change in voltage magnitude along line

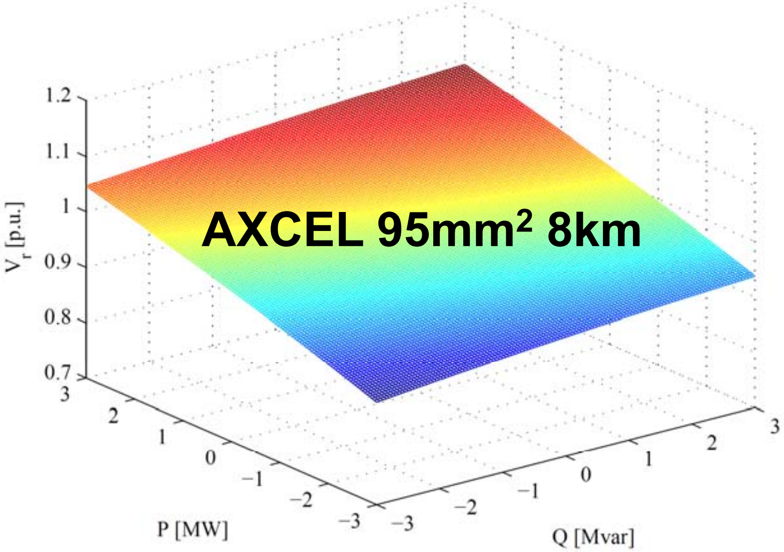


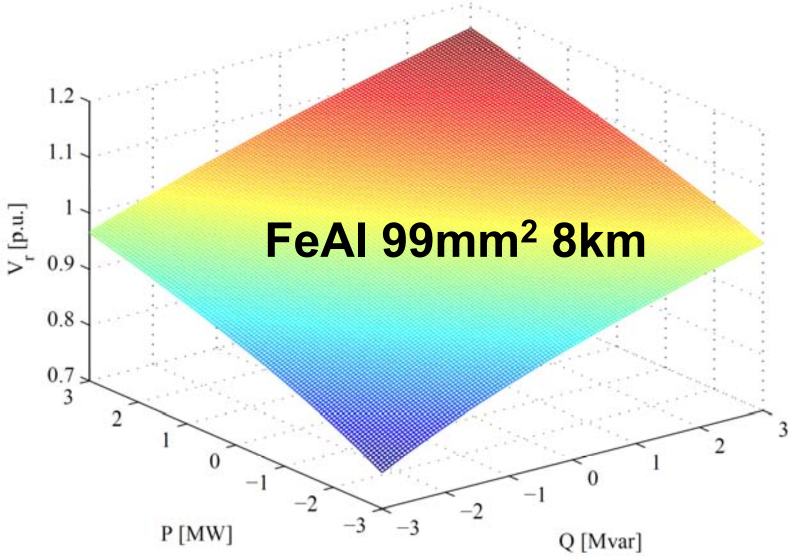
$$\Delta V_{line} \approx R_{line} I_p + X_{line} I_q \approx \frac{R_{line} P_r + X_{line} Q_r}{V}$$

- At transmission level reactive power controls voltage
- At distribution level Q normally required to be zero
- Draw Q should be possible with power electronics

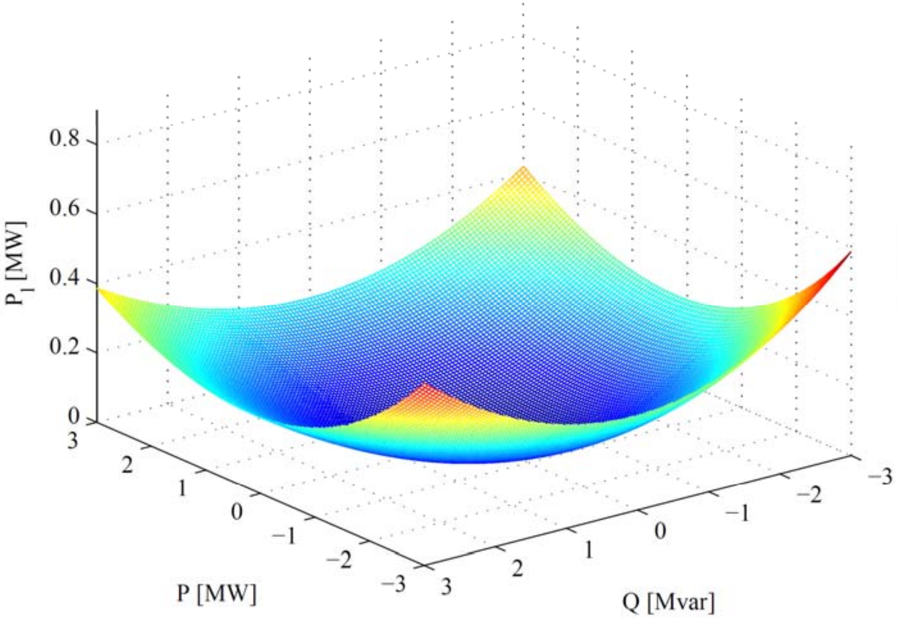
Medium Voltage lines

Line type	R [Ω/km]	L [mH/km]	C [μF/km]	X/R
Cable AXCEL 95mm^2	0.320	0.35	0.21	0.34
Cable AXCEL 150mm^2	0.206	0.32	0.24	0.49
OHL FeAl 99	0.336	1.085	0.0061	1.01
OHL FeAl 157	0.214	1.036	0.0061	1.52

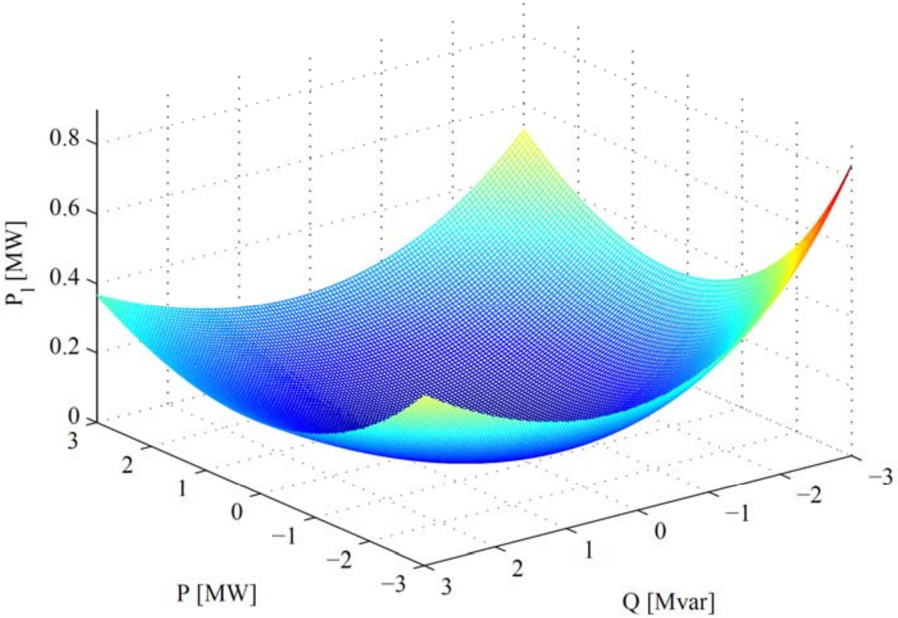




Network losses

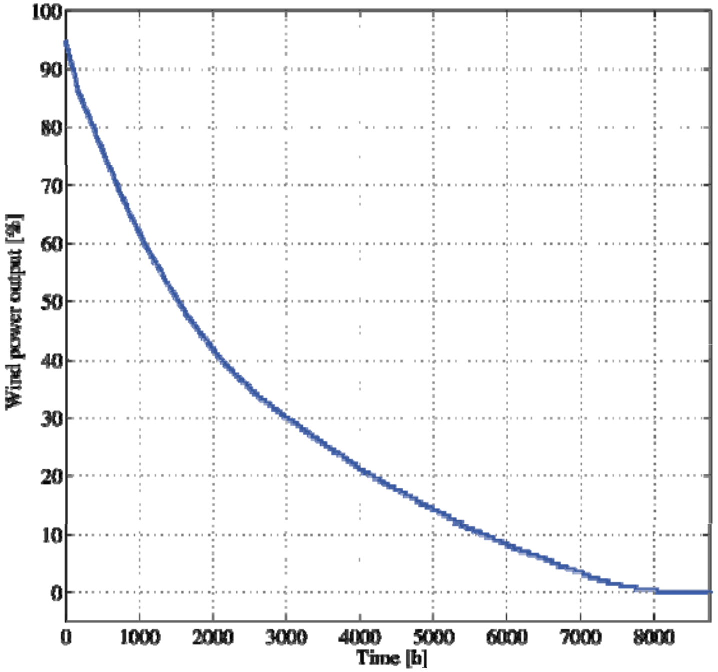


AXCEL 95mm^2 8km



FeAl 99mm^2 8km

How frequent is maximum generation?



- Some curtailment of active power is reasonable

Use all actuators in a coordinated way

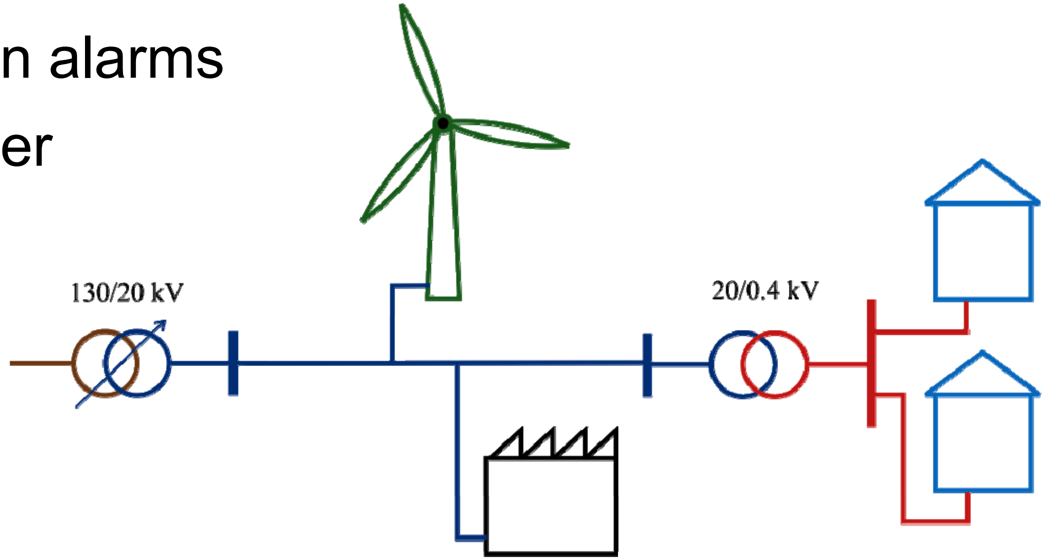
- On-load Tap Changer
    - ± 9 steps 1.67 % each → ±15 % in entire network
- Reactive Power
    - Local effect
    - But increases line currents and thus losses
    - PF=0.89 or variable
- Active Power Curtailment
    - Root cause – always works
    - But reduces income to generator owner

Voltage requirements

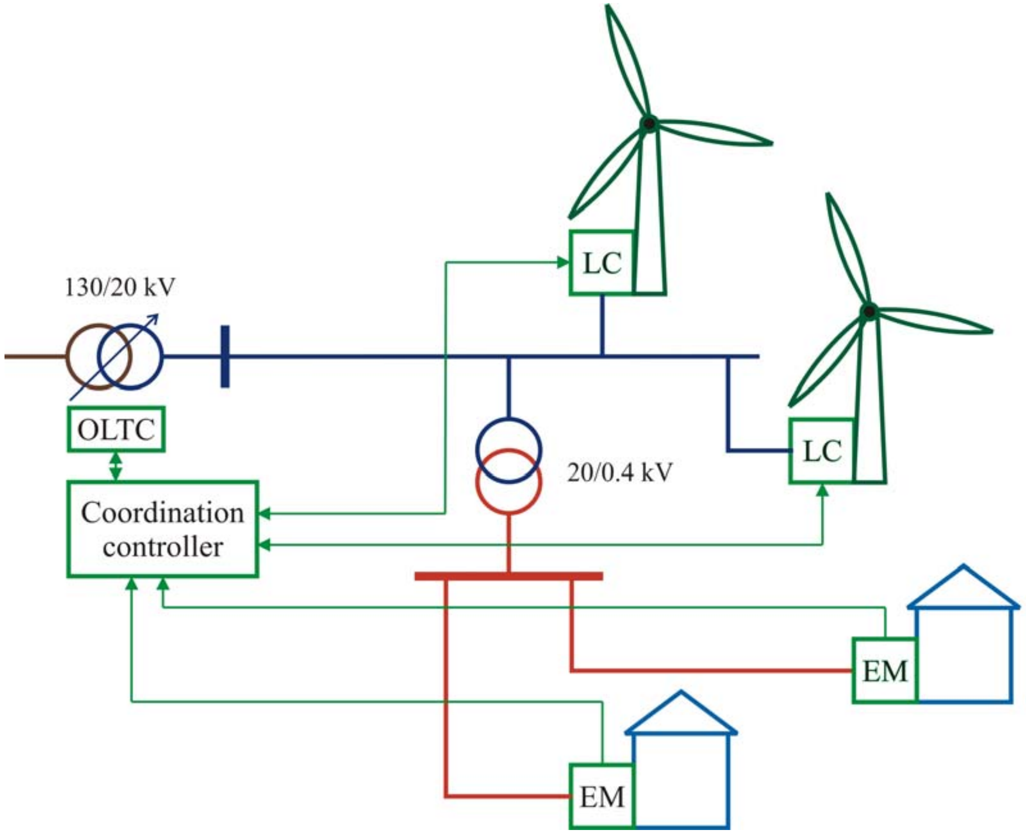
- EN 50160
  - Voltage quality at customer side
  - +/- 10 % for 95 % of a week with 10 min RMS values

New electricity meters can report voltage

- Remote reading of energy once a month since July 2009
  - Urban: PLC, ZigBee
  - Rural: GPRS
- Additional features
  - Voltage limit violation alarms
  - Operate main breaker
  - Control output

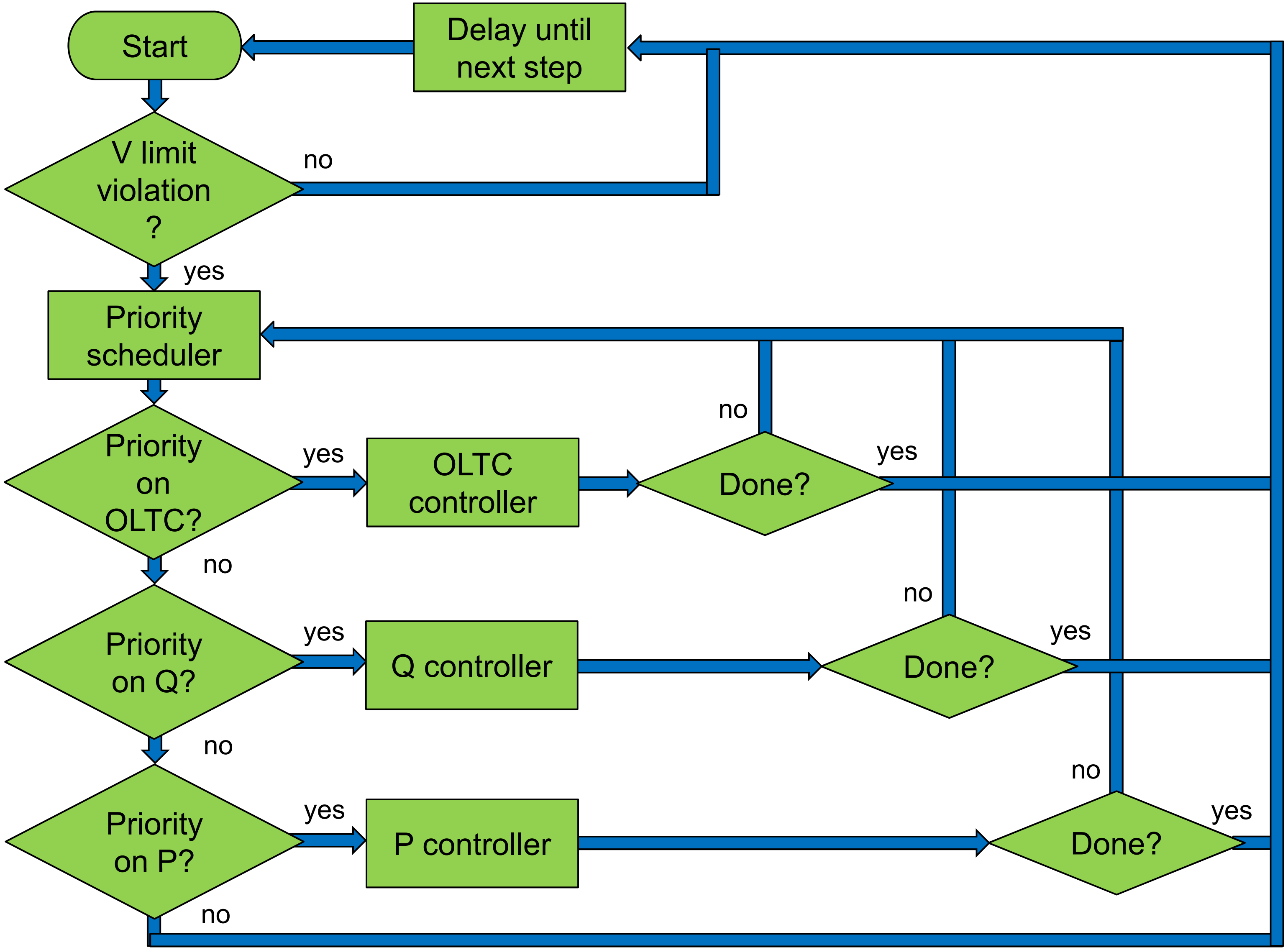


Proposed control structure



130 kV line
20 kV line
0.4 kV line
Control and communication
Distributed Generation
Load

Heuristic algorithm uses incremental control

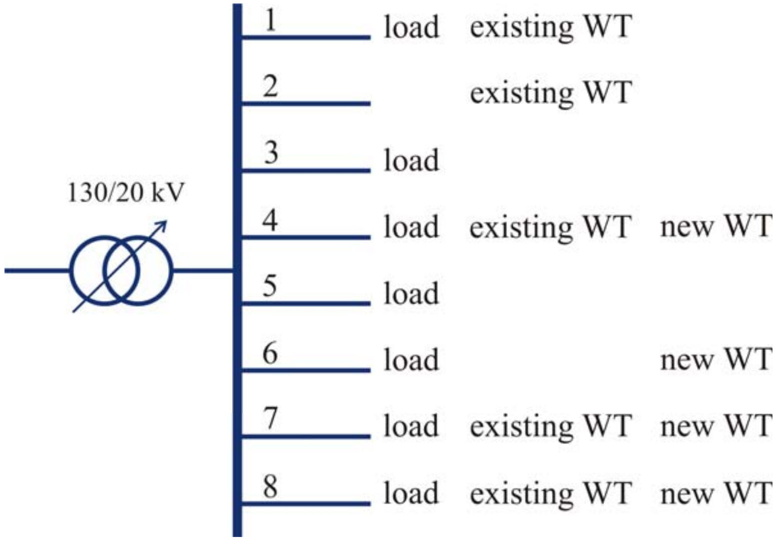


Result indicators

- Installed MW windpower
- Delivered and curtailed MWh windpower
- Tap operations
- Losses in MWh

E.ON test case

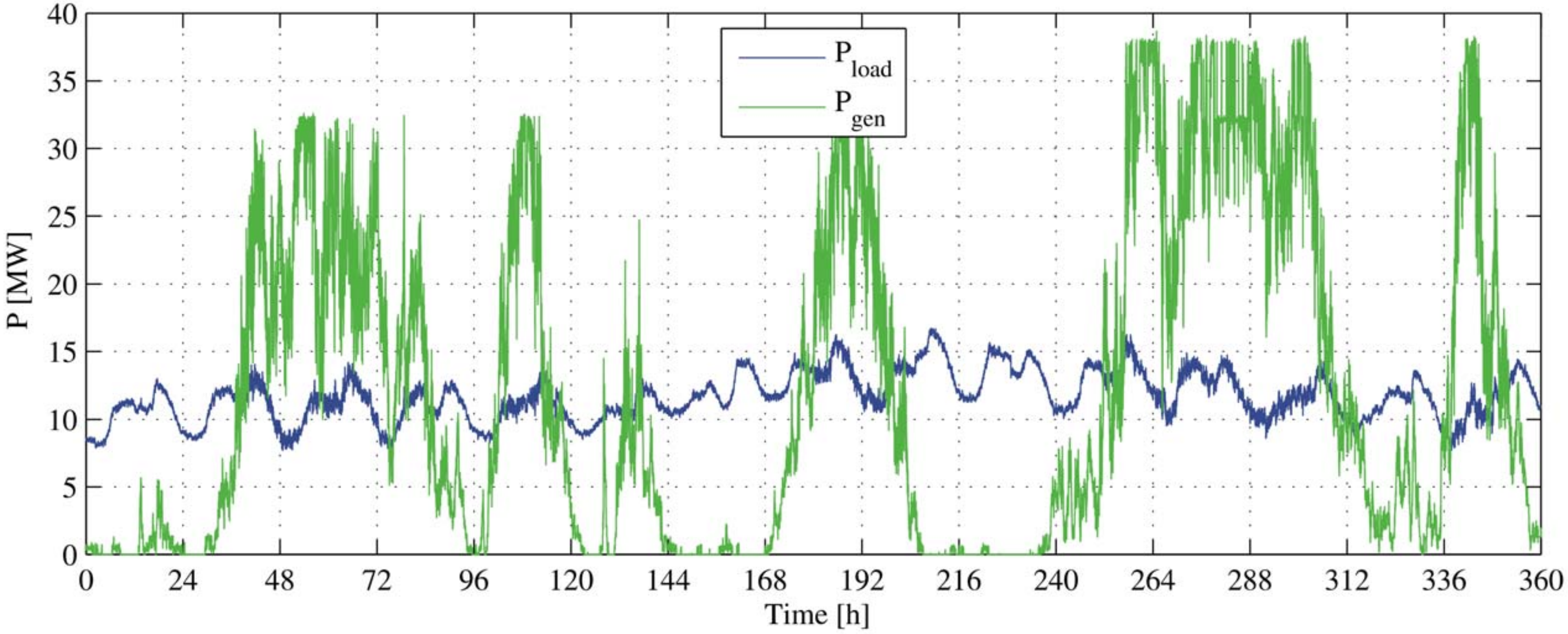
Feeder	Load [MW]	Existing WT [MW]	New WT [MW]
1	5.8	0.7	0.0
2	0.0	9.0	0.0
3	5.1	0.0	0.0
4	1.7	0.9	6.0
5	4.0	0	0.0
6	1.9	0	3.0
7	5.3	1.4	13.0
8	4.2	0.8	3.0
∑	28.0	12.8	25.0



E.ON test case

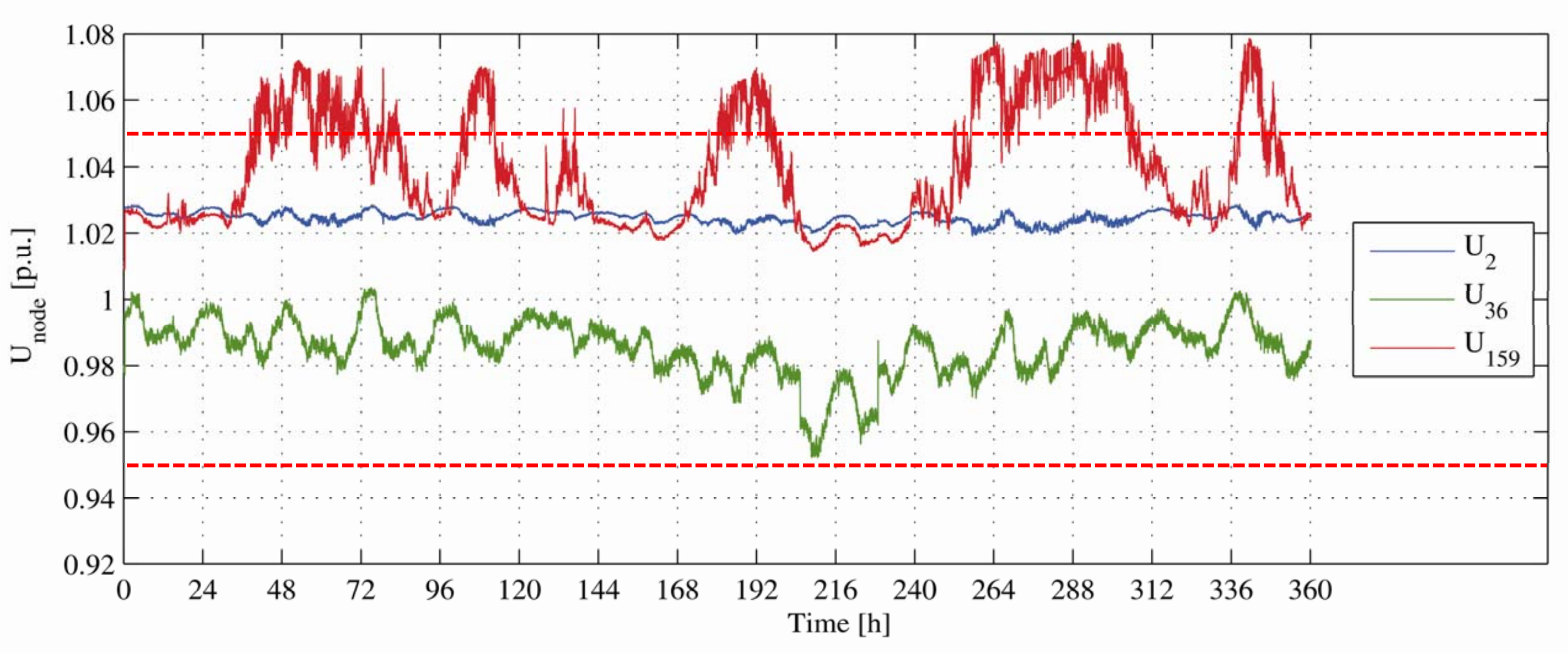
- 130/20 kV E.ON substation
- 8 feeders
- 3 substations 20/10 kV
- ~250 Medium Voltage nodes
- ~170 substations 20/0.4 kV
- Load between 5 MW and 28 MW
- Windpower 13 MW installed and 25 MW to be added

E.ON load and generation profiles



Total active power load (measured)
Total active power generation (measured values upscaled)

E.ON test case voltages with only tap changer

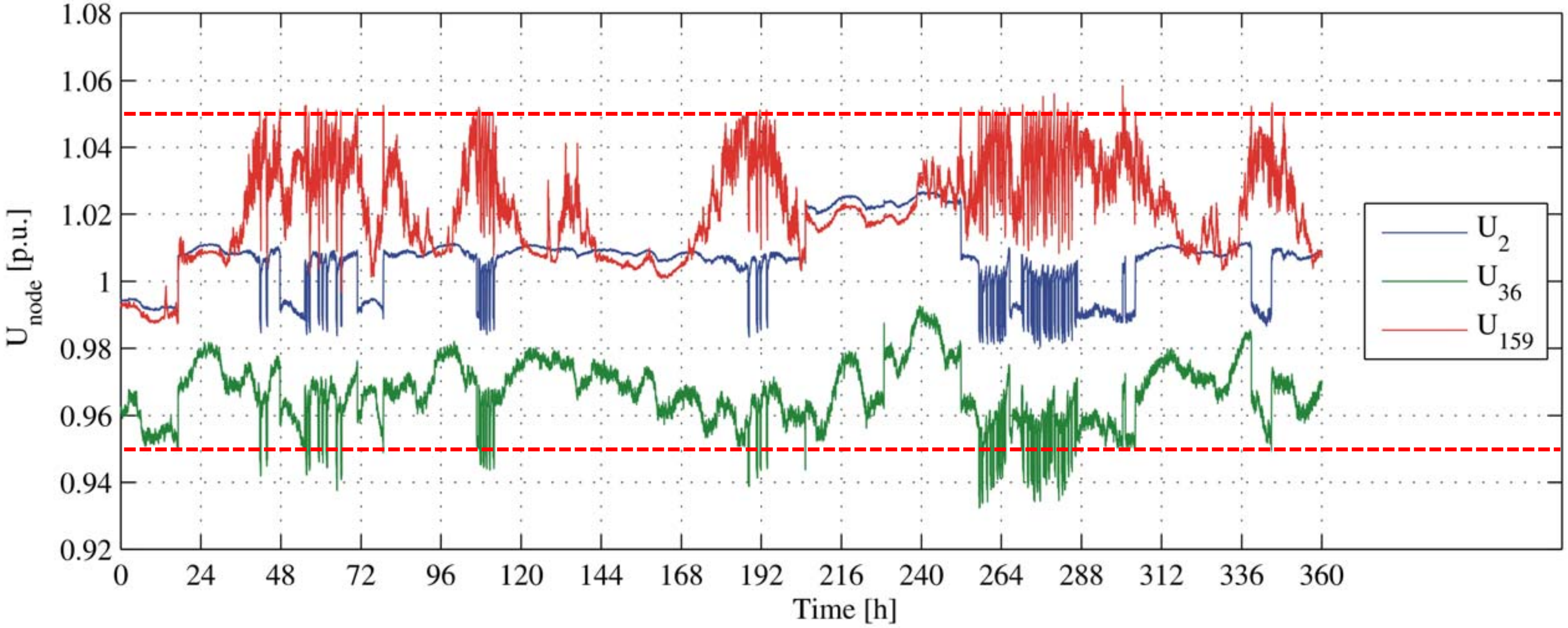


Voltage at substation busbar with normal setpoint

Voltage at node with lowest voltage

Voltage at node with highest voltage

E.ON test case voltages with new control

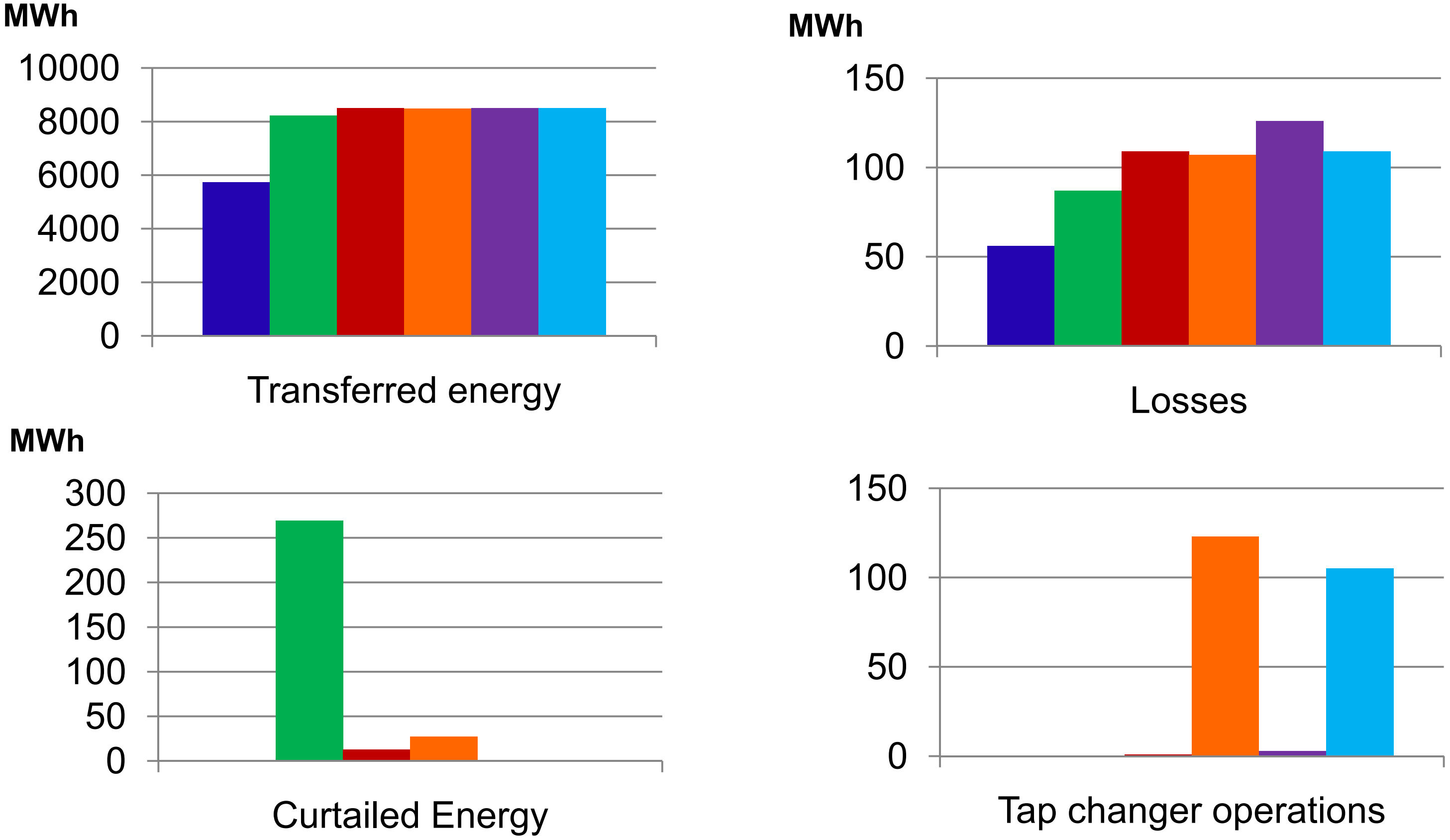


Voltage at substation busbar

Voltage at node with lowest voltage

Voltage at node with highest voltage

E.ON test case results

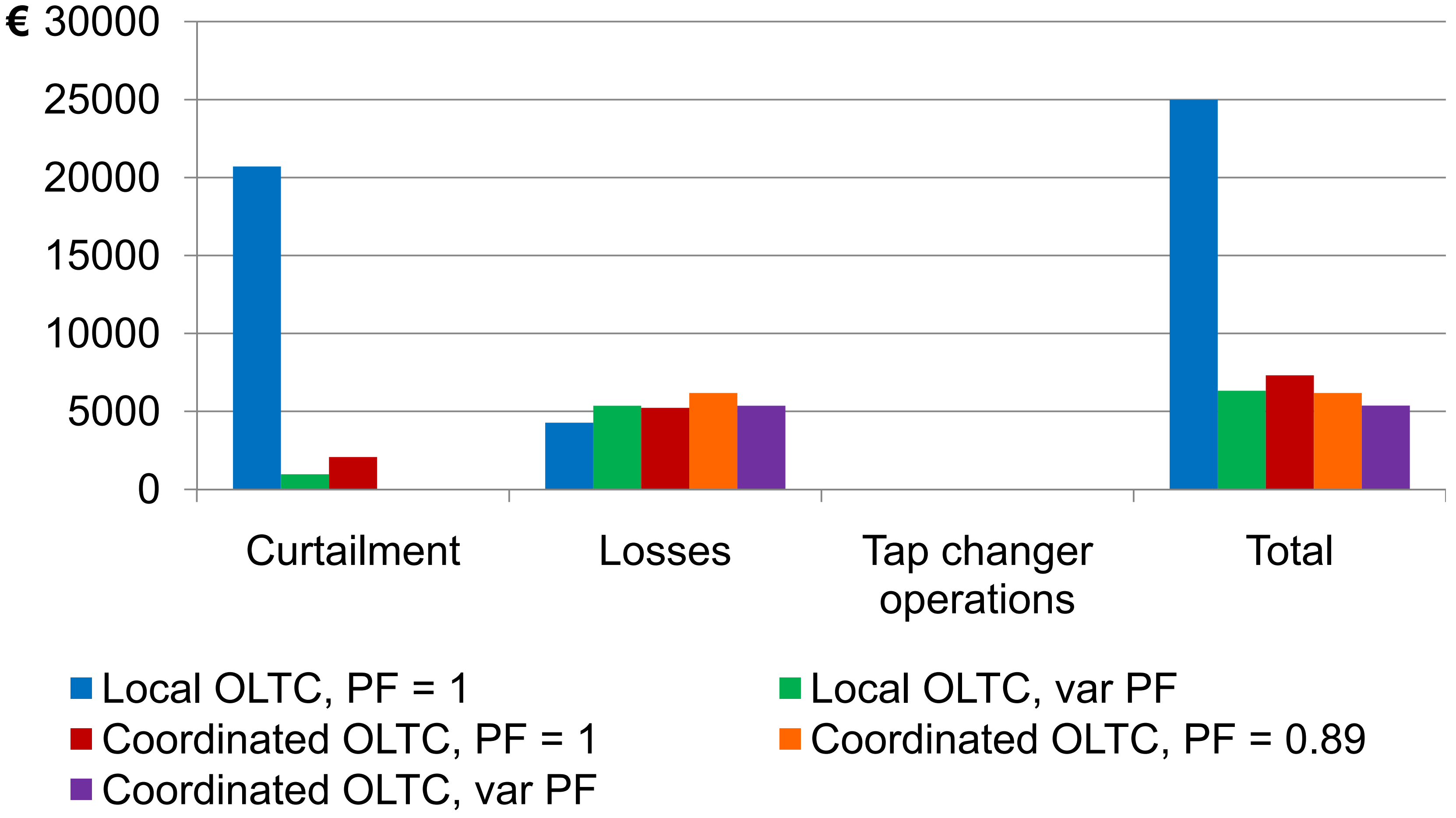


Local OLTC, existing windpower
Local OLTC, PF=1
Local OLTC, PF var
OLTC with EM, PF=1
OLTC with EM, PF=0.89
OLTC with EM, PF var

E.ON test case economic analysis

- Costs for tap operations
  - Maintenance costs
- Costs for network losses
  - MWh price at NordPool
- Costs for active power curtailment
  - MWh price at NordPool
  - Electricity certificates

E.ON test case economic results



Conclusions

- Increase of windpower capacity without reinforcement
- 12.8 MW + 25 MW (14.3 MW) = 37.8 MW (27.1 MW)

  → increase of windpower 75 % additional, 40 % total
- Economical benefits from coordinated OLTC and variable PF
- Energy values critically depends on profiles

- Use of electricity meters feasible
- Alarms difficult and discrete control not optimum
- Voltage magnitude and some continuous control better