Power Network Investment Planning Considering Deep Uncertainty

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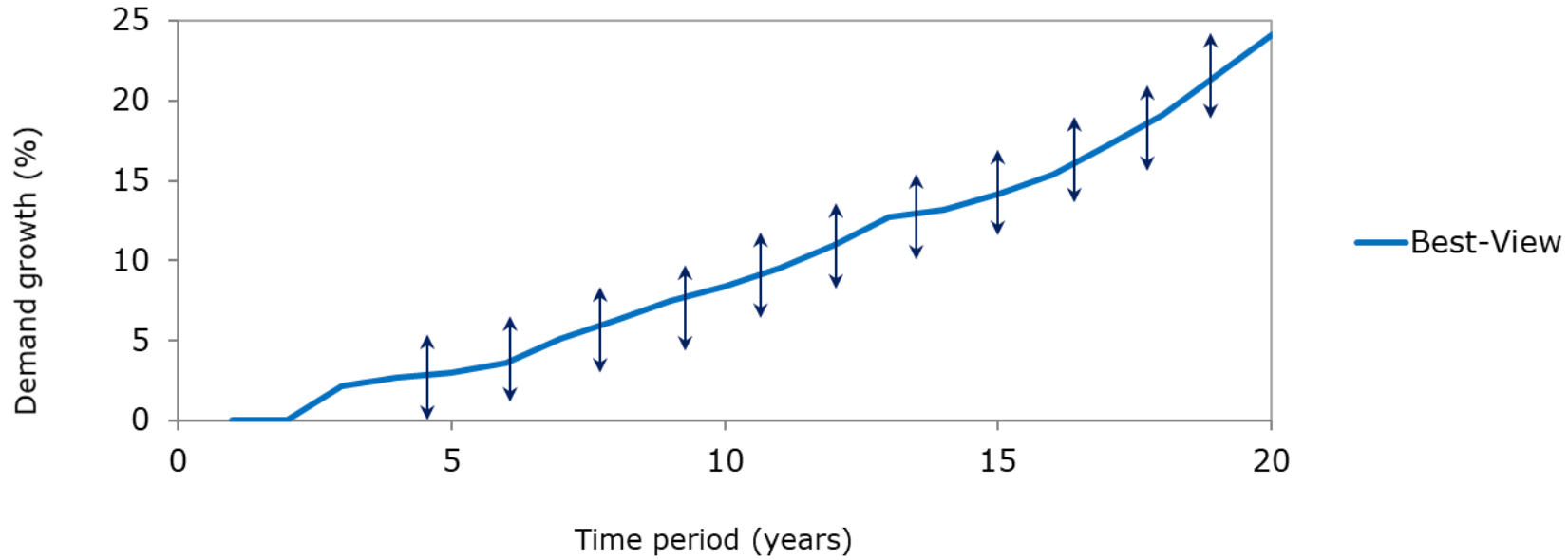
What is deep uncertainty in the context of investment planning?

Traditional demand growth – Deterministic?

How do we see the future?

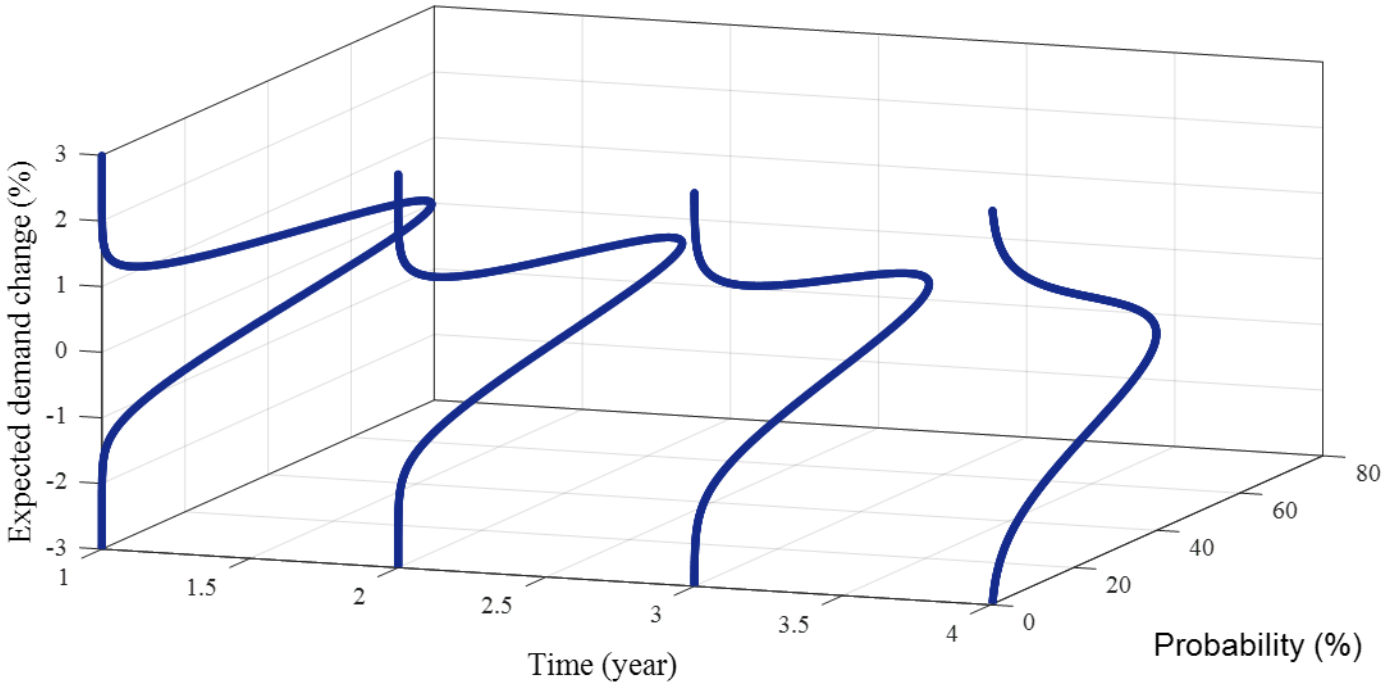
- Deterministic: There is a best-view future, and potential variations could be explored with sensitivity studies



Traditional demand growth – Probabilistic?

How do we see the future?

- Probabilistic: There are multiple potential futures which can be assigned probabilities, e.g., can be modelled with probability density functions

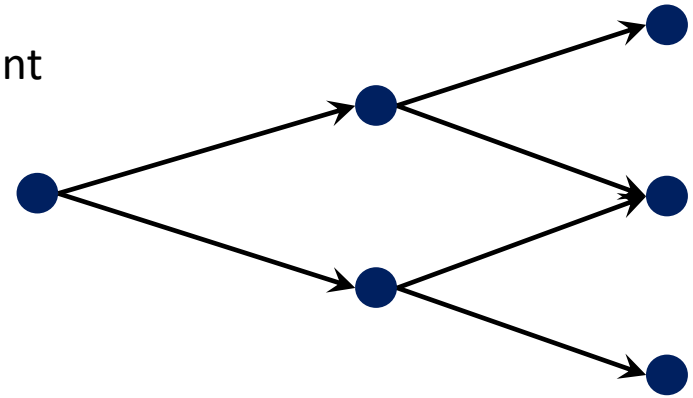


Levels of uncertainty: Deep Uncertainty?

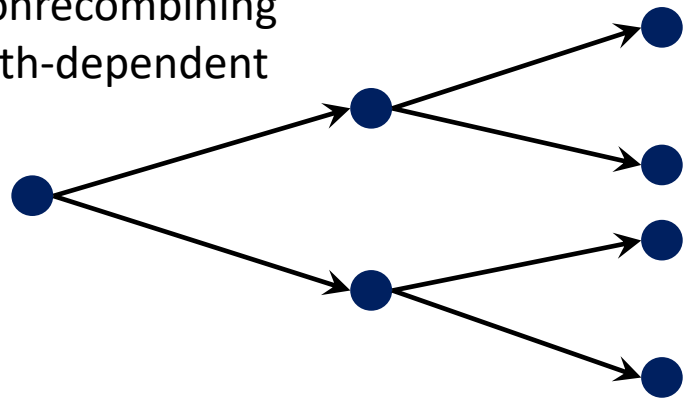
How do we see the future?

- Deep uncertainty: There are multiple potential futures which can be significantly different, or may have unknown probabilities.

Decisions do NOT impact the future
Recombining
Path-independent



Decisions impact the future
Nonrecombining
Path-dependent



- Unknown: There is no consensus about how the future may look like

Dealing with uncertainty:

What can we do for our investment projects to cope with the uncertain future?

- Not much, only design the project and expect it performs well
  - ➢ We need robustness: The performance of the system should be relatively good under most or all potential conditions
    - Fit-and-forget approach
    - Now-or-never decisions
- We can monitor and constantly update the project in response to changes in the future
  - ➢ We need Flexibility: The project should be planned to customisation, which is required to ensure good performance under different scenarios
    - Adaptive approach
    - Multi-stage decisions

Adaptive planning under deep uncertainty

Example: Investments in distributed energy resources (DER)

- Flexibility is only valuable in the face of uncertainty
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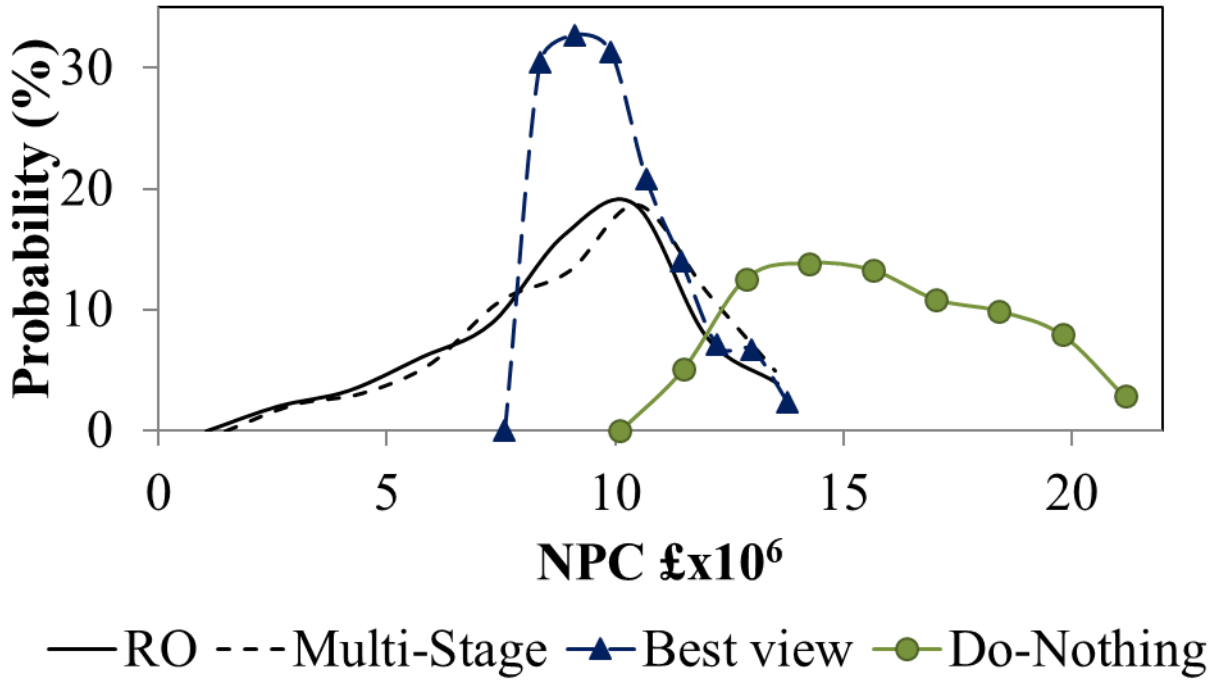
- However,
  - ➢ Traditional approaches undermine the value of flexibility (Best-view)
  - ➢ Adaptive approaches maximise the value of flexibility (multi-stage and RO)



E. A. Martinez Cesena, T. Capuder and P. Mancarella, "Flexible distributed multi-energy generation system expansion planning under uncertainty," IEEE Transactions on Smart Grid, 2016,

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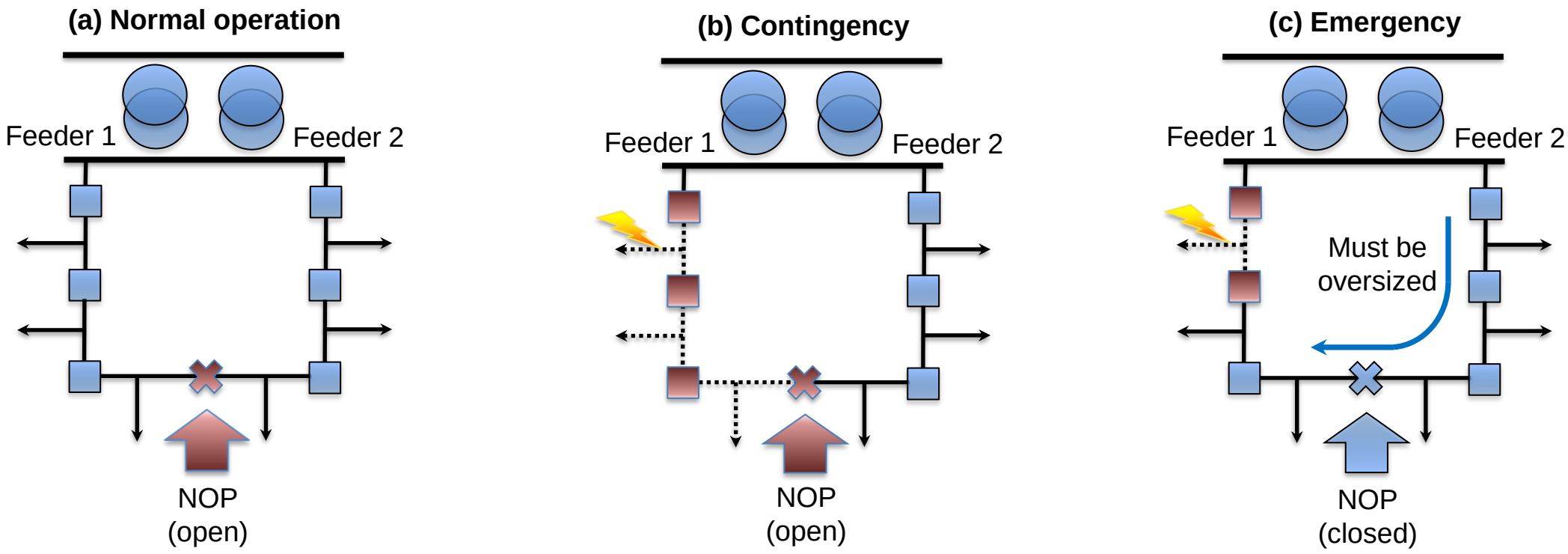
Distribution network planning

Medium voltage distribution networks

Operation of the MV (6.6 kV and 11 kV) distribution networks in the UK

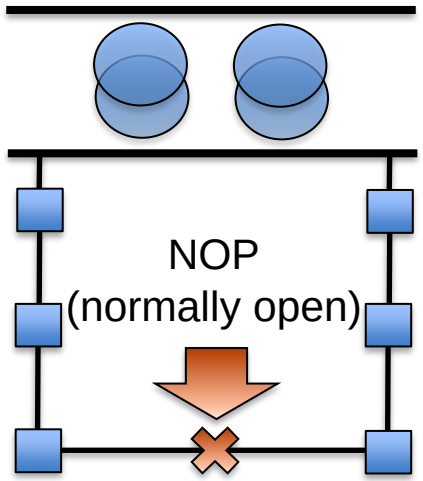
- Does this make sense if we consider DER flexibility?



Flexible MV distribution networks

Operation of the MV (6.6 kV and 11 kV) distribution networks in the UK considering DER flexibility

Considering traditional customers

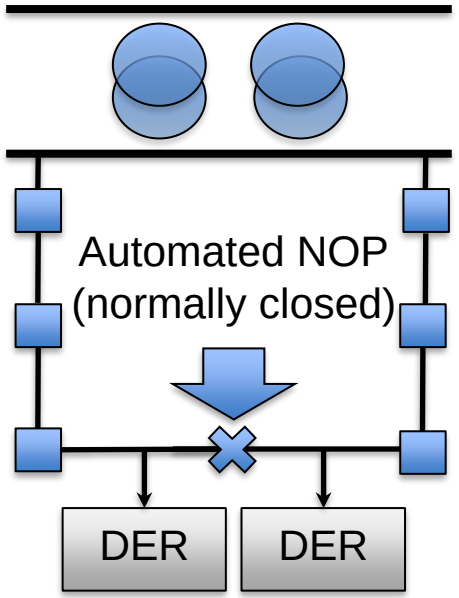


Loads:
Inflexible

Constraints:
Preventive security
Thermal
Voltage

Expectations:
–

Considering flexible customers



Loads:
Inflexible
Interruptible

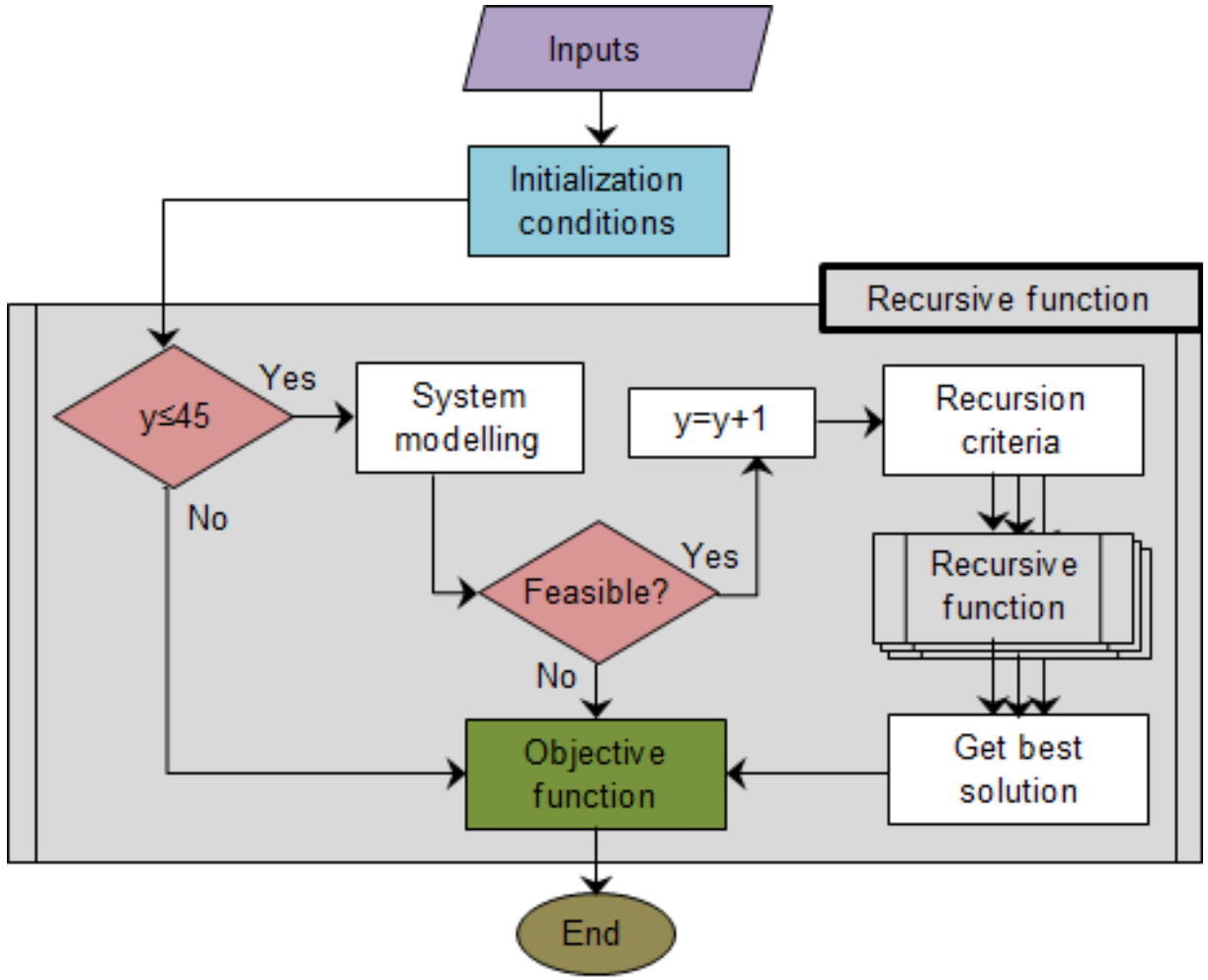
Constraints:
Corrective security
Thermal
Voltage

Expectations:
Increased capacity
Higher reliability
Reduced power losses

Optimisation engine

Characteristics:

- Recursive approach
- Flexible SMINLP formulation
- Computationally tractable
- Optimality guaranteed



EAMC and PM, "Practical Recursive Algorithm and Flexible Open-Source Applications for Planning of Smart Distribution Networks with Demand Response," *Sustainable Energy Grids and Networks,* Vol. 7, pp. 104 –116, 2016.

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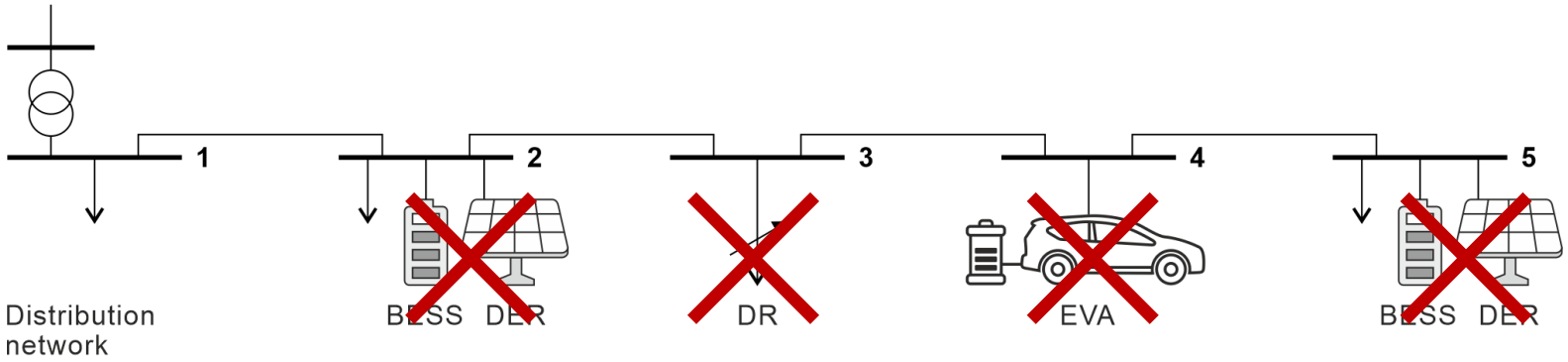
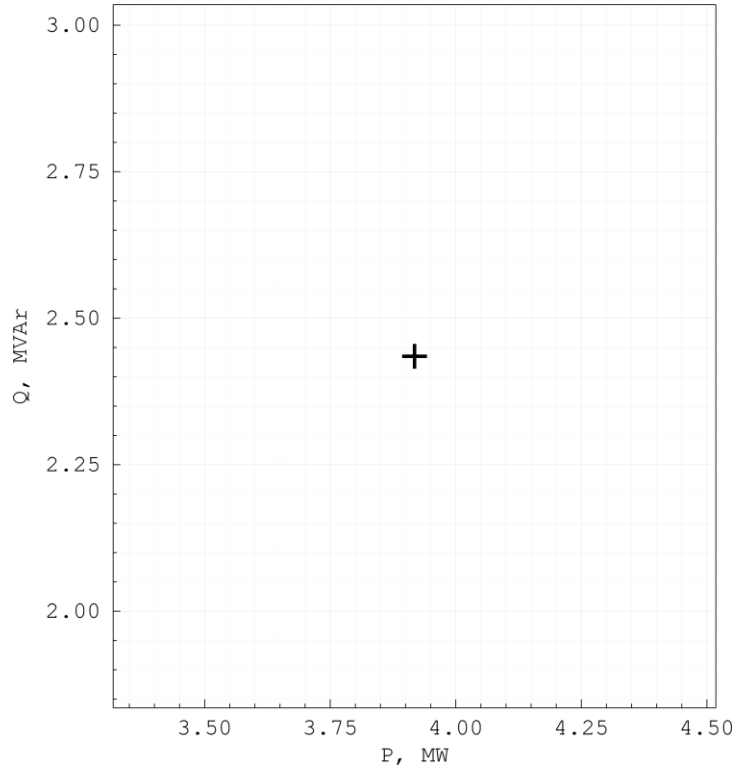
Network investment planning tools

The value of DER flexibility

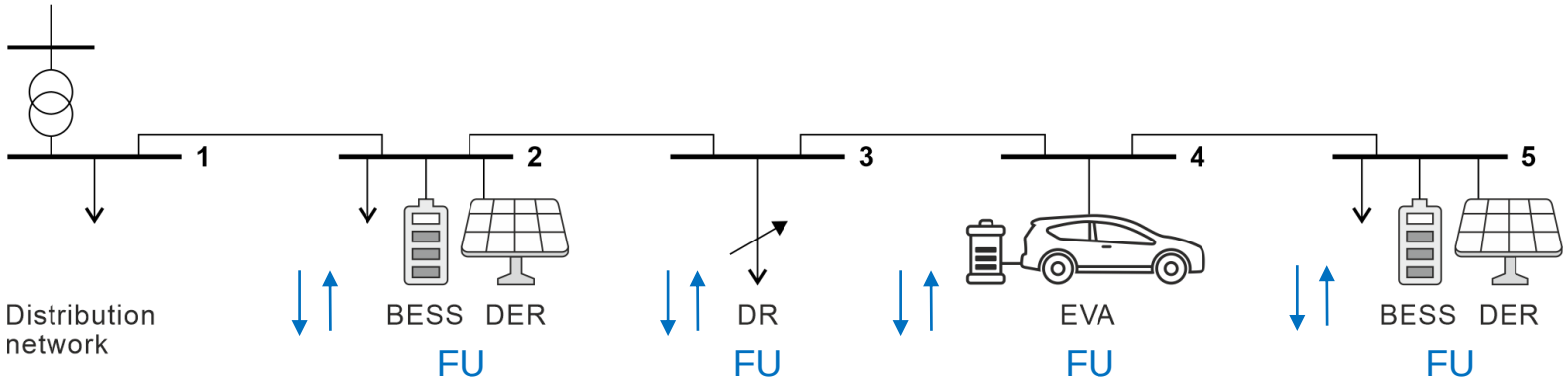


Passive distribution network – designed to accept bulk power from transmission system and distribute to customers

Aggregated network flexibility:



The value of DER flexibility



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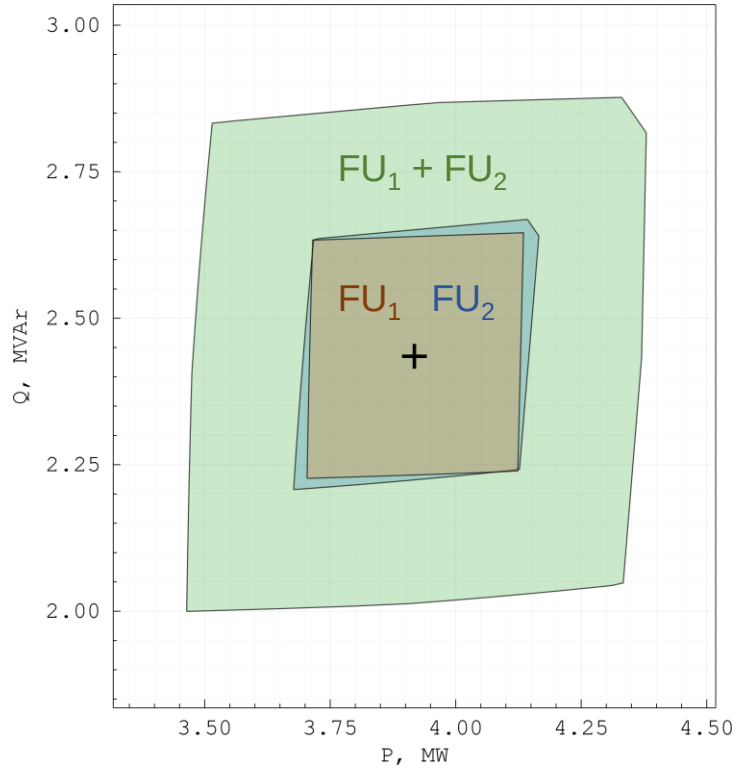


Flexible units – have the technical ability to regulate their power exchange with the grid

Distribution networks transform into active distribution networks (ADNs)

Network flexibility can be aggregated and used both at the distribution and transmission levels, e.g., at the TSO/DSO interface.

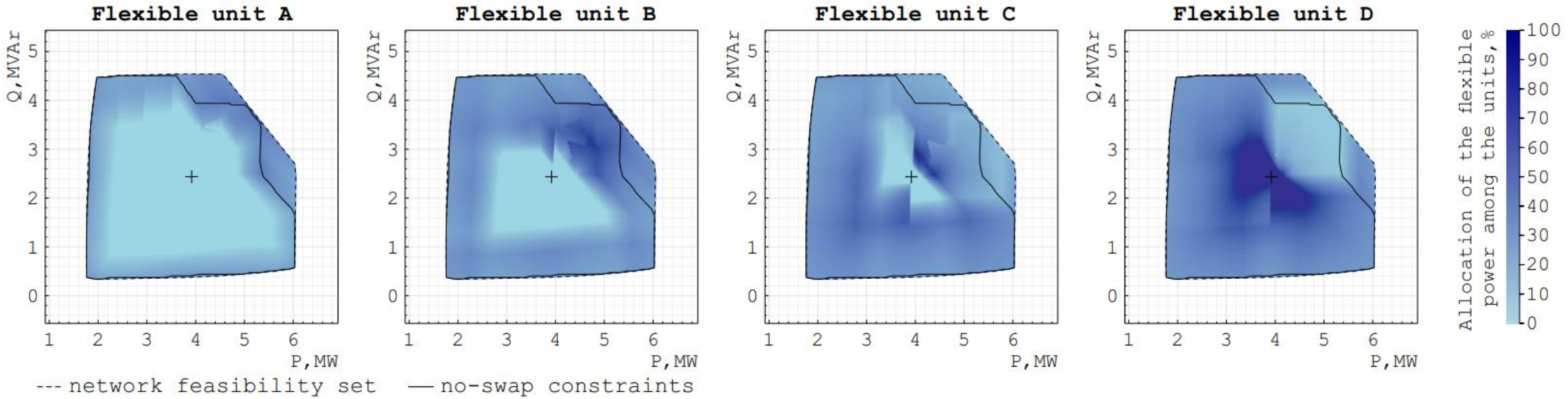
However, ADNs bring multiple challenges, such as:

- Estimation of feasible network operating points
- Voltage control issues
- Tracing and pricing flexible power within distribution networks

The value of DER flexibility

Example: IEEE 33-bus test system (a 12.66kV radial distribution network) with 4 flexible units

Allocation of the flexible power according to the cost-based OPF model, in %:



Note: The cheapest units get activated more often and are allocated more power and payments
Note: The power-swap phenomenon happens when multiple units provide flexible power under network constraints

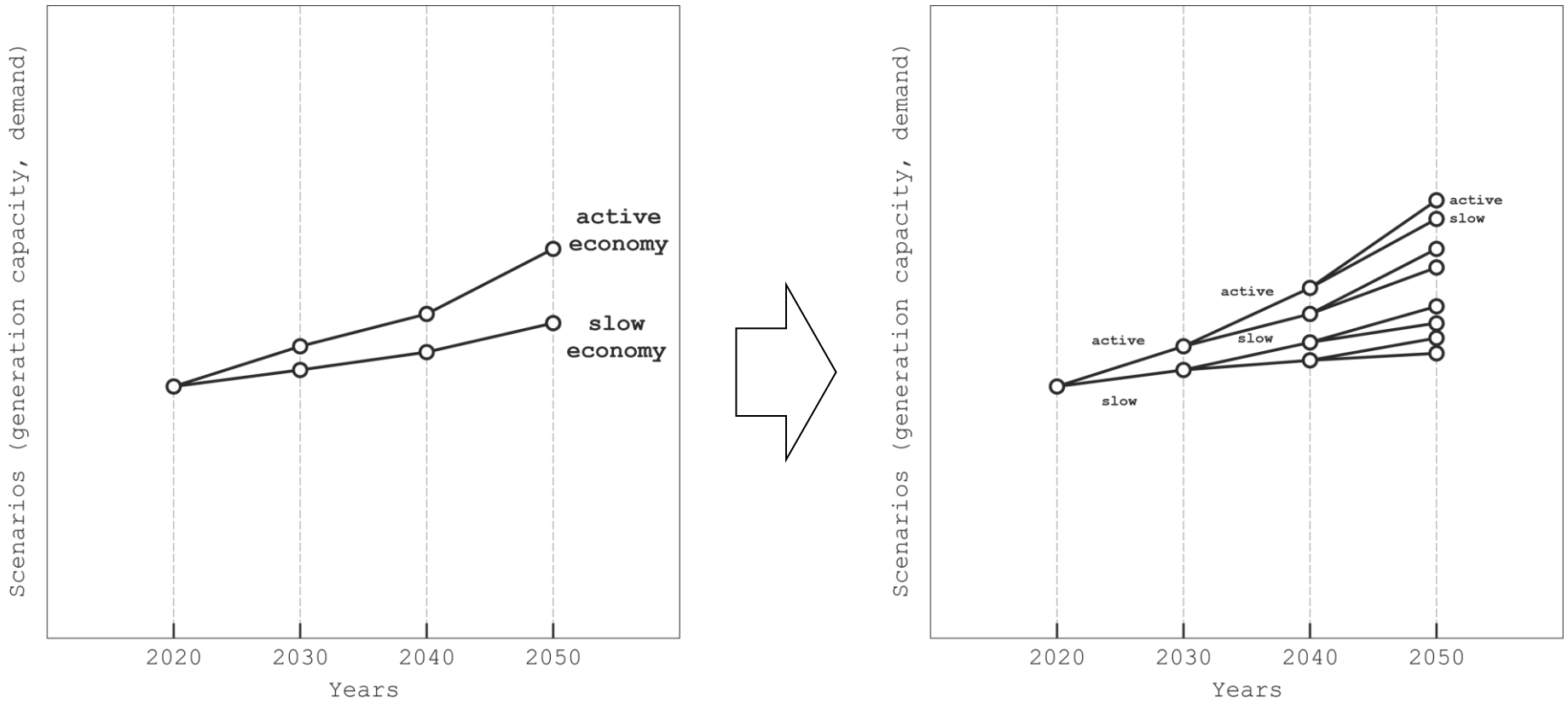
Andrey Churkin, Wangwei Kong, Jose N. Melchor Gutierrez, Eduardo A. Martínez Ceseña, Pierluigi Mancarella, "Tracing, Ranking and Pricing DER Flexibility in Active Distribution Networks," 2022, https://arxiv.org/abs/2210.03589

Application: ATTEST project

How can network planning tools capture the value of flexibility?

Application: ATTEST project

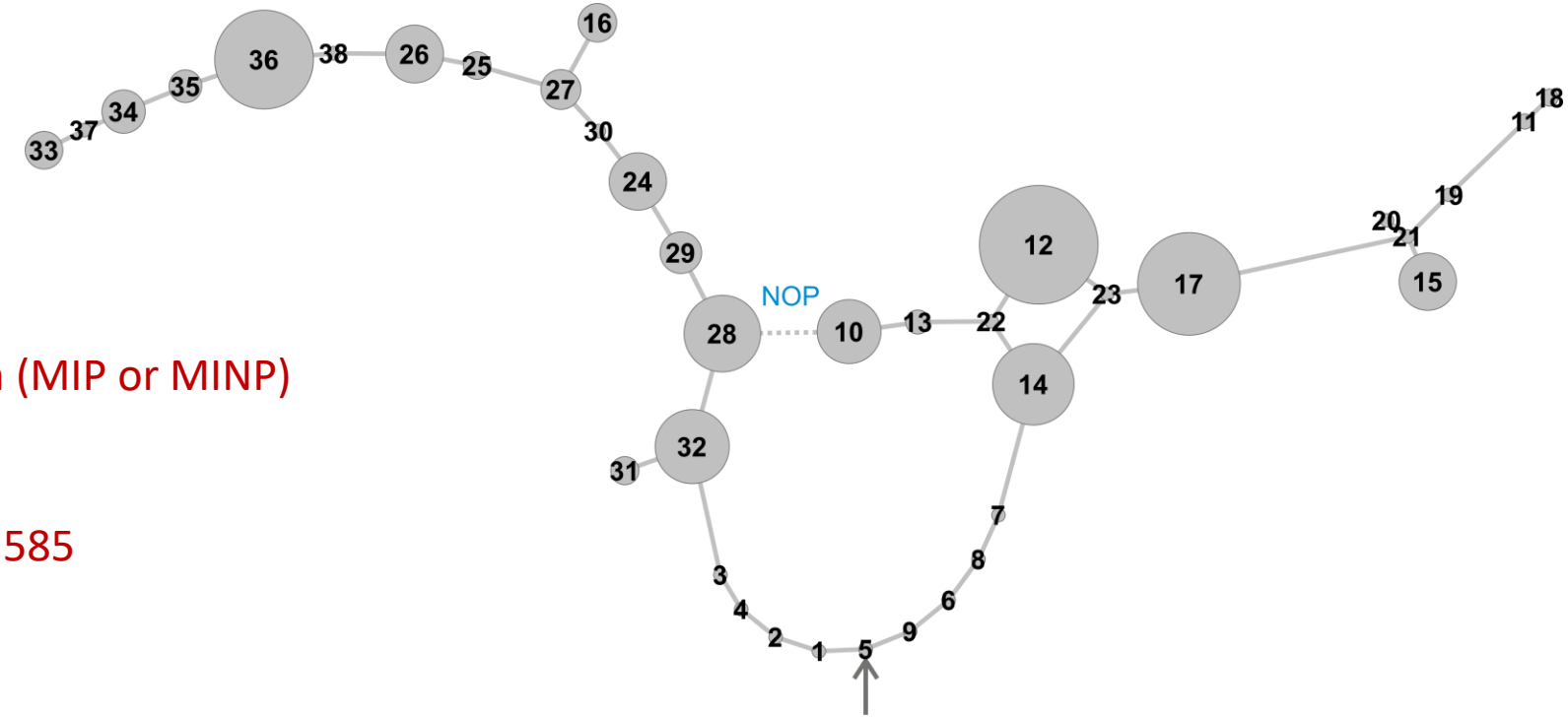
Capturing demand growth uncertainty via the path-dependent scenario tree:



Application: ATTEST project

Example: *"Distribution_Network_Semi_Urban_UK.m"*

- Total load of 5.47 MW
- 39 lines
- 1 generator – primary substation
- 2 feeders, 1 normally open point



Hard combinatorial optimization problem (MIP or MINP)

Large number of binary variables:

39 lines * 15 nodes in the scenario tree = 585

Application: ATTEST project

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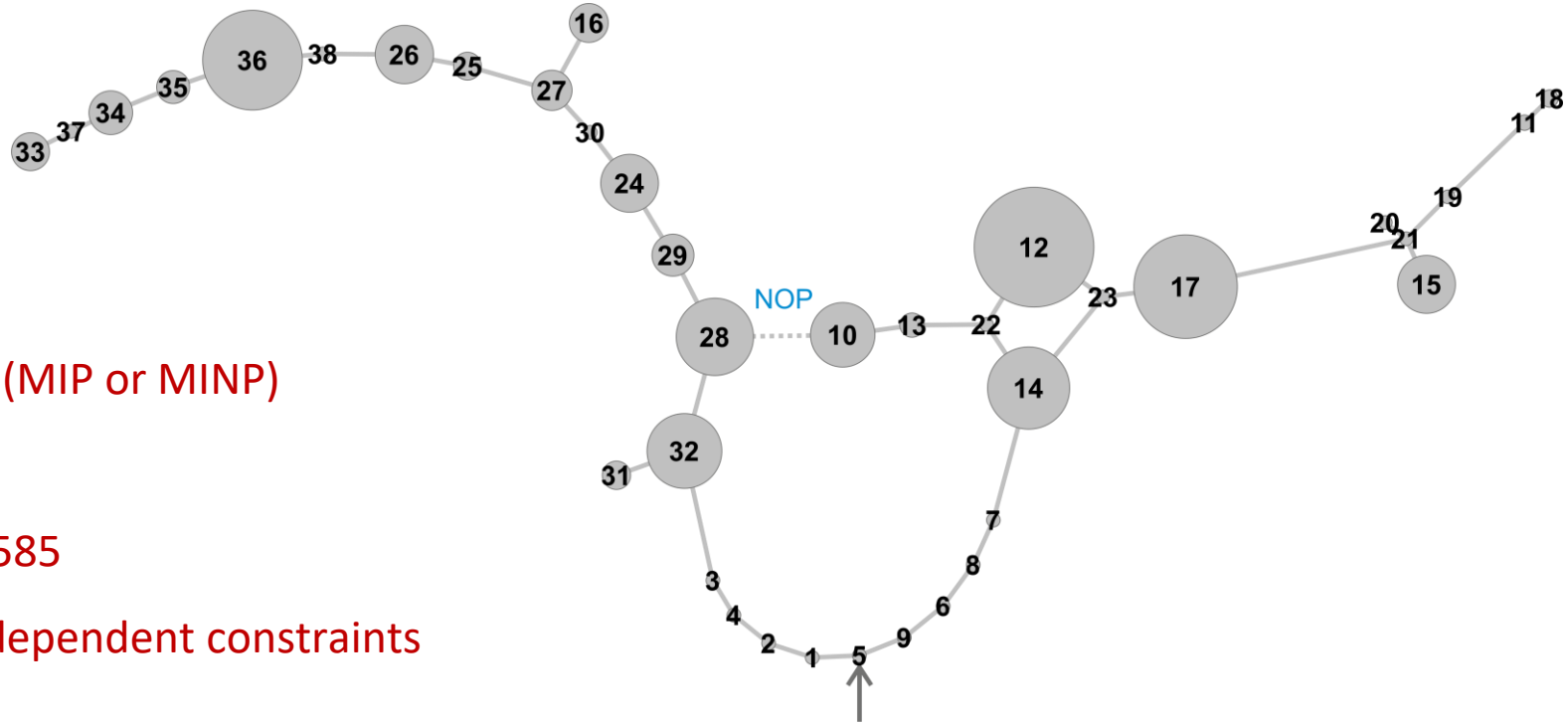

Hard combinatorial optimization problem (MIP or MINP)

Large number of binary variables:

39 lines * 15 nodes in the scenario tree = 585

* 26 investment options = 15,210 + time-dependent constraints

Investment catalogue:

[0.003,0.006,0.009,0.015,0.03,0.045,0.075,0.1125,0.15,0.225,0.3,0.5,0.75,1.0,2.0,5.0,10.0,20.0,
30.0,40.0,50.0,60.0,80.0,100.0,250.0,500.0] (MW)

Application: ATTEST project

Example: *"Distribution_Network_Semi_Urban_UK.m"*

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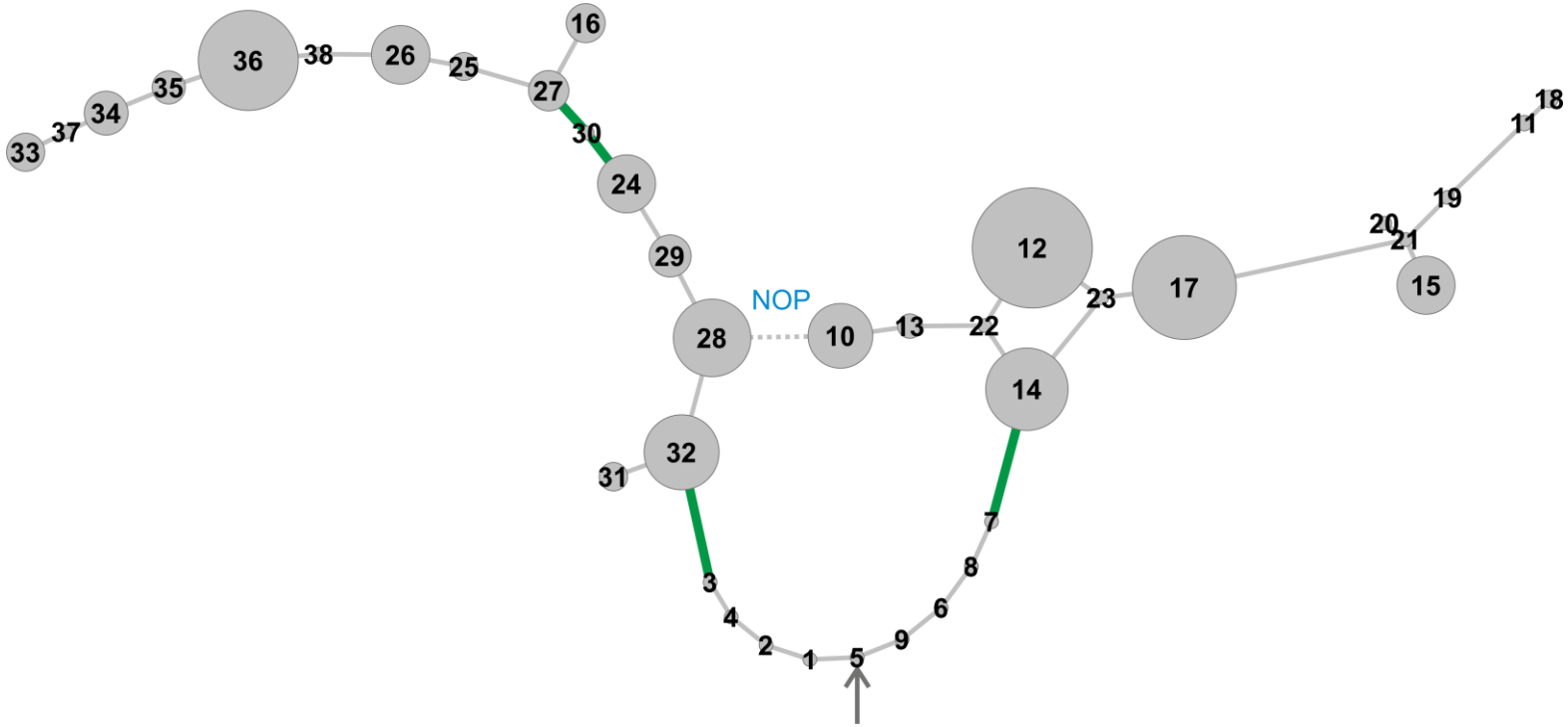
Solution:

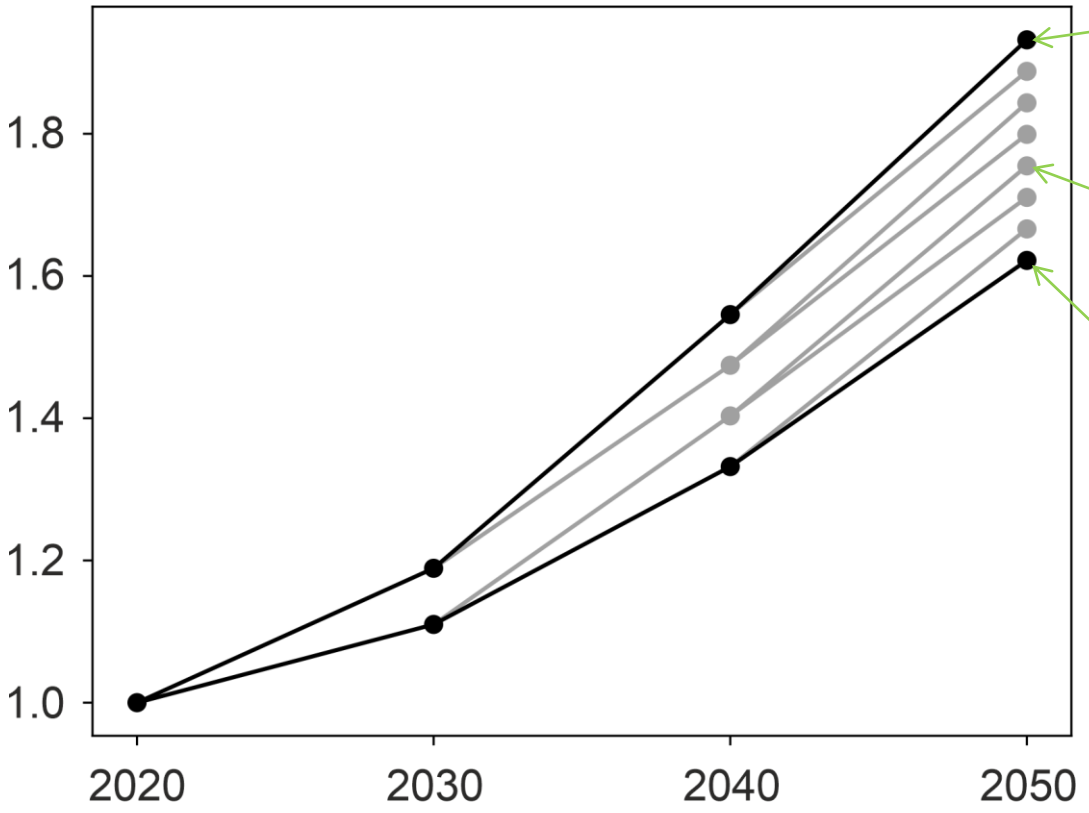
- Screening & clustering modules
- Recursive function

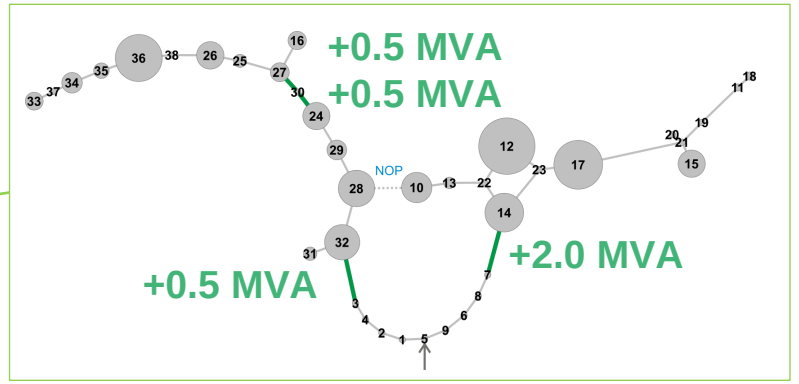


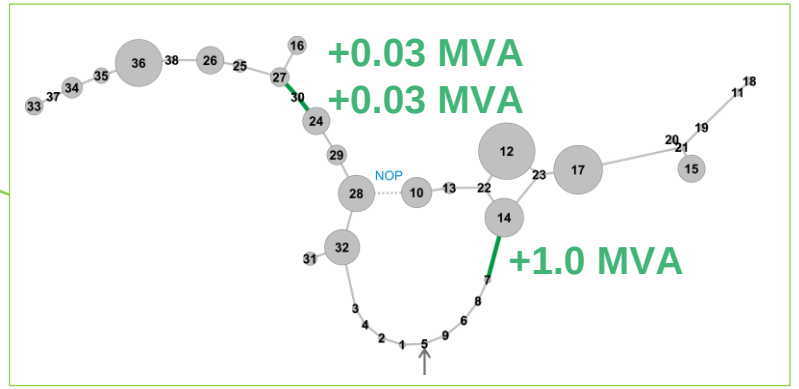
The screening model identifies that only **4 lines** will require investments, in the range 0.03-2.0 MVA

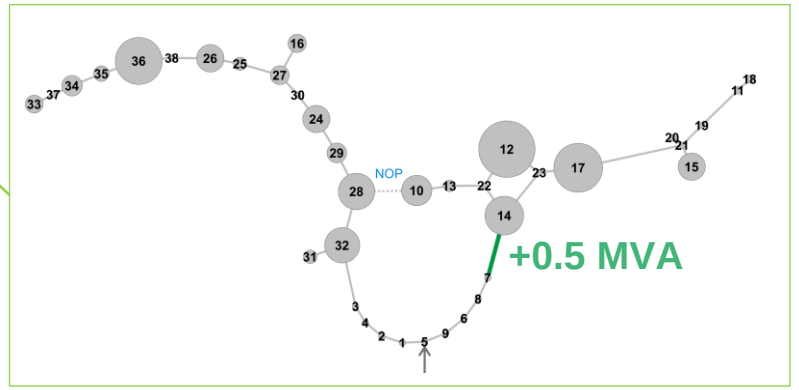
Application: ATTEST project

UK case scenario multipliers:









Your questions