Study Committee C1

Power System Development and Economics

Paper 10708_2022

Advanced IT Tools for Distribution Network Resilience Improvement: The X-FLEX Project Demo in Xanthi

G. I. TSIROPOULOS*1, D. G. STRATOGIANNIS1, S. GKIALA – FIKARI1, M. CHAMPAKIS1

D. N. TRAKAS2, E. PAPOUTSIS2, V. BANOS2, A. L. A. SYRRI2, N. D. HATZIARGYRIOU2

1 Hellenic Electricity Distribution Network Operator S.A. (HEDNO)

2 National Technical University of Athens (NTUA) / Institute of Communication and Computer Systems (ICCS)

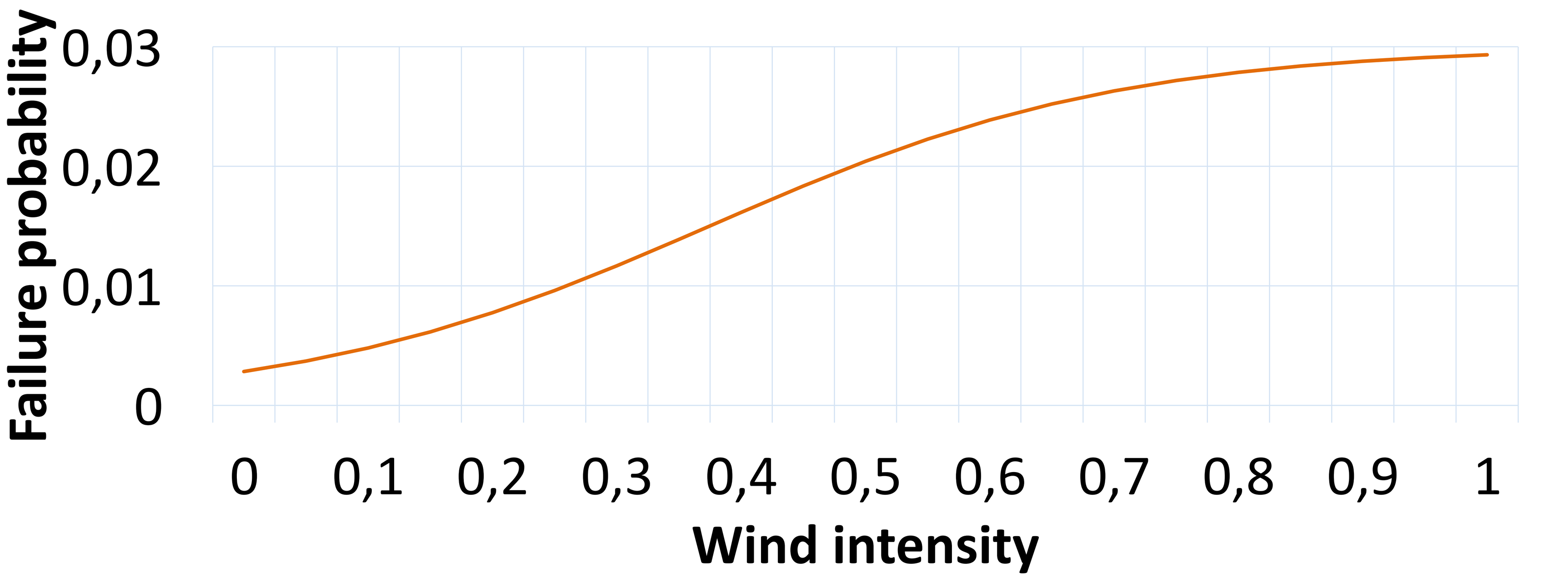
Motivation

- In 2021, a severe ice storm in Greece caused major failures of 45 MV lines leading to outages and the disconnection of more than 70.000 households due to the fall of trees on distribution lines.
- Electric power utilities and especially Distribution System Operators (DSOs) are strongly interested in increasing power grid resilience.
- Advanced technological solutions are required for system operators to assess system resilience and determine the proper measures to mitigate the impact on system and increase system resilience.

Contribution/Novelty

- We propose the general architecture of an advanced tool that can be used by a DSO to assess distribution system resilience.
- The optimal utilization of Distributed Energy Resources (DERs) is considered to increase distribution system resilience.

Figure 1: Fallen tree-induced fragility curve



Modelling the Impact of Weather Event

- Fragility curves are used to obtain the failure probability of a system component as a function of the weather intensity, w.
- The function of the fragility curve

$$p_{ftr}(w) = A * \frac{e^{h(w)}}{1 + e^{h(w)}}$$

$$h(w) = a_s + c_s w D_H b_s$$

- A is the average tree-induced damage probability of overhead lines. It depends on:
  - the distance of the trees from the line,
  - the number of the trees around the lines,
  - the length of the line.

Resilience Assessment

- A resilience indicator is used to quantify the resilience level of the system as a function of time.
- $\boldsymbol{R_0}$ is the pre-disturbance resilience level and is assumed to be equal to 100% and $\boldsymbol{R_d}$ is the degraded resilience level at the end of the extreme weather event.
- After the restoration, it is assumed that the resilience indicator is fully recovered.
- Resilience is quantified as the ratio between the system performance (area between horizontal axis and the graph of the resilience indicator) and the targeted performance (area between horizontal axis and $\boldsymbol{R_0}$).

Study Committee C1

Power System Development and Economics

Paper 10708_2022

Advanced IT Tools for Distribution Network Resilience Improvement: The X-FLEX Project Demo in Xanthi

continued

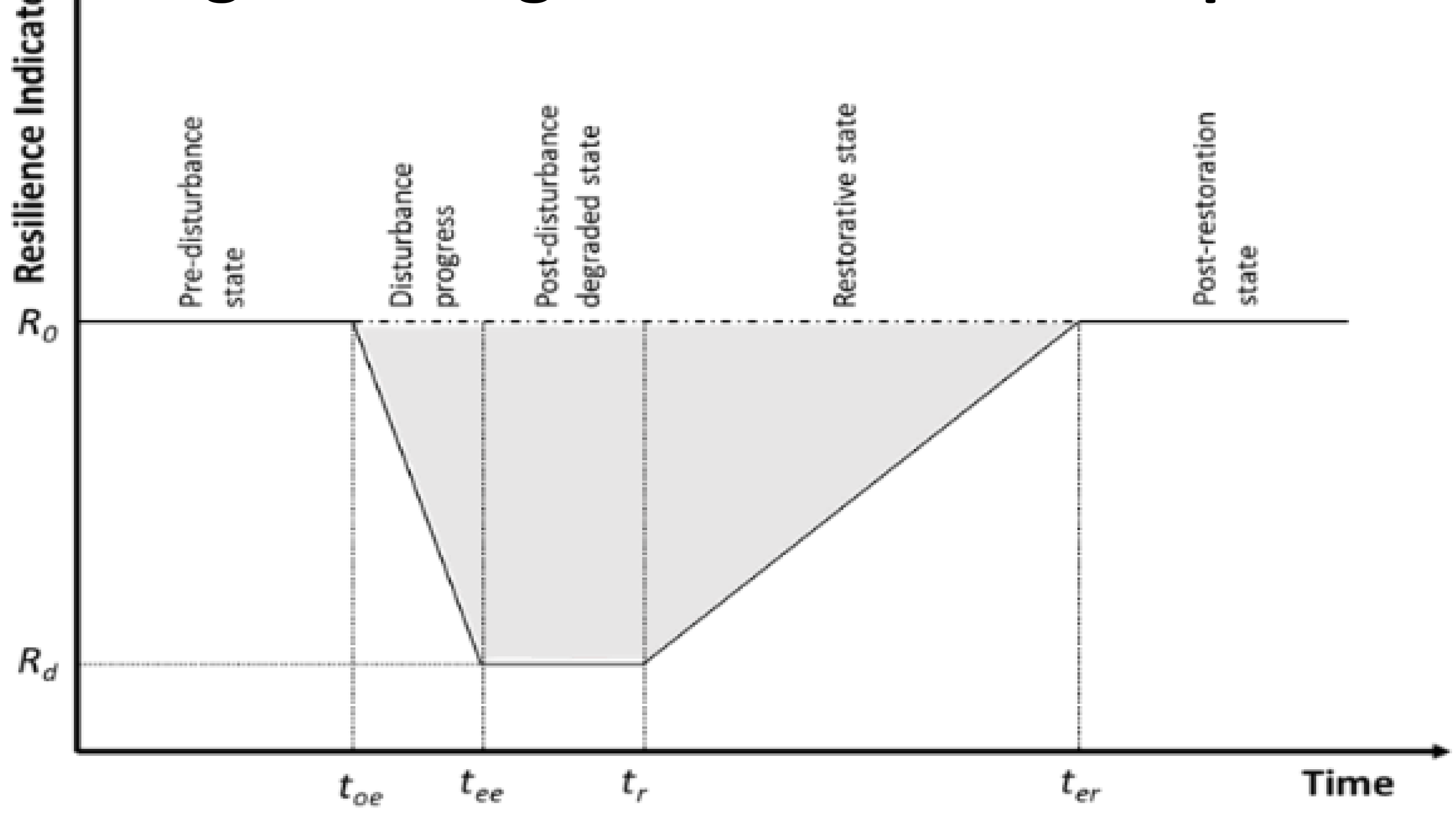
Resilience Assessment (continued)

- The smaller the area of the resilience trapezoid in Figure 2 (shaded area), the better the resilience performance of the system.
- The three phases that the system might reside:
  - Disturbance progress: It is the phase between the beginning, t_{oe} , and the end, t_{ee} , of the external threat (e.g., extreme weather event).
  - Post-event degraded state: It is the phase following the end of the event, t_{ee} , and before the initiation of system restoration, t_r.
  - Restorative state: It is the phase following the initiation of the restoration, t_r, until the full recovery of the resilience indicator, t_{er} .

Problem Formulation

- A Monte Carlo simulation is used to deal with the uncertainties of line failures.
- A uniformly random number $r_i \sim U(0, 1)$ is generated for line i at each time interval. If the failure probability of the line, obtained from the fragility curve, is larger than r, then it is tripped.
- If a line has tripped, its restoration initiates after the end of extreme weather due to safety reason.
- It is considered that a repair crew is needed for each damaged line and the repair crew is committed for as many hours as needed to repair a line according to MTTR.
- The sequential order of line restoration is determined based on the criticality of the line.
- An optimization problem is solved to determine the minimum load shedding carried out at each time interval.
- The network topology and the system technical constraints are considered in the optimization problem. It considers the DERs connected to the distribution system, such as Renewable Energy Resources and batteries, to enhance the operational resilience of the system.
- The results of the Monte Carlo simulation are used to calculate the resilience metrics and design the resilience trapezoid.

Figure 2: A generic resilience trapezoid.



Case Study

- The area of Xanthi is being supplied by two main HV/MV substations of 200 MVA in total.
- The length of the overhead MV and LV network is 1,302 km and 1,330 km, respectively.
- The MV underground network has length of 42 km, while the LV underground network has a total length of 115 km, most of which can be found within the city of Xanthi.
- There are 1,934 MV/LV distribution substations with total capacity of 244,410 kVA (82,005 kVA within the city of Xanthi).
- The pilot spreads over three MV feeders of the local distribution network, thoroughly selected in order to facilitate the implementation of the use cases and to examine the effectiveness of the developed algorithm and tools.
- In particular, the medium voltage feeder 33X is used.

Three Cases

- Case I: It is considered that 4 repair crews are available. The average MTTR of damaged lines after extreme weather is 5 hours.
- Case II: 3 repair crews are considered, while the MTTR is considered equal to 4.
- Case III: The effect of line robustness against extreme weather is examined. The parameter A of the fragility curve is set equal to 0.06 (instead of 0.03), decreasing the robustness of the lines. 3 repair crews are considered and MTTR is equal to 5.

Study Committee C1

Power System Development and Economics

Paper 10708_2022

Advanced IT Tools for Distribution Network Resilience Improvement: The X-FLEX Project Demo in Xanthi

continued

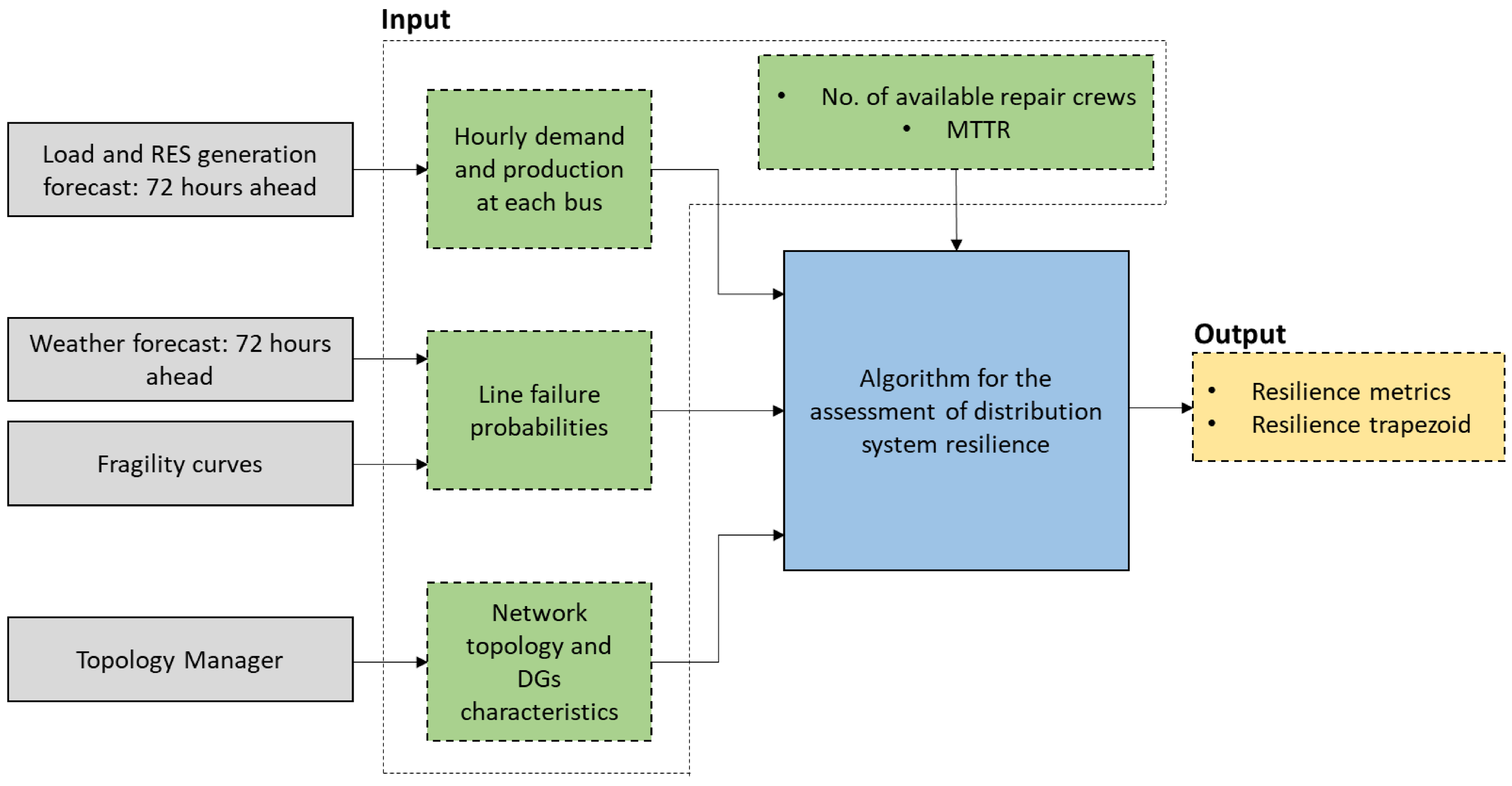


Figure 3. General structure of the developed resilience assessment tool.

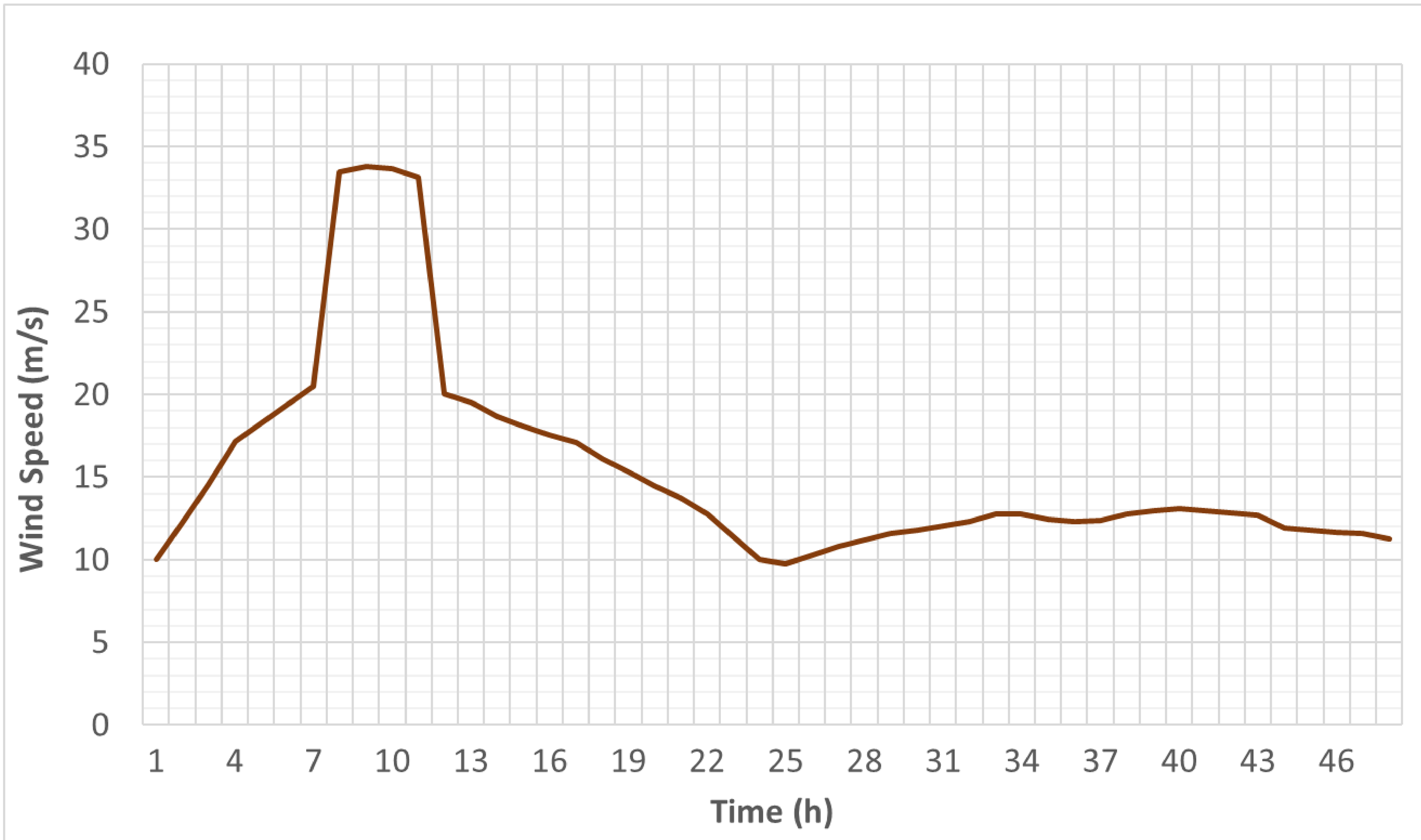


Figure 4. Wind speed within vulnerable areas.

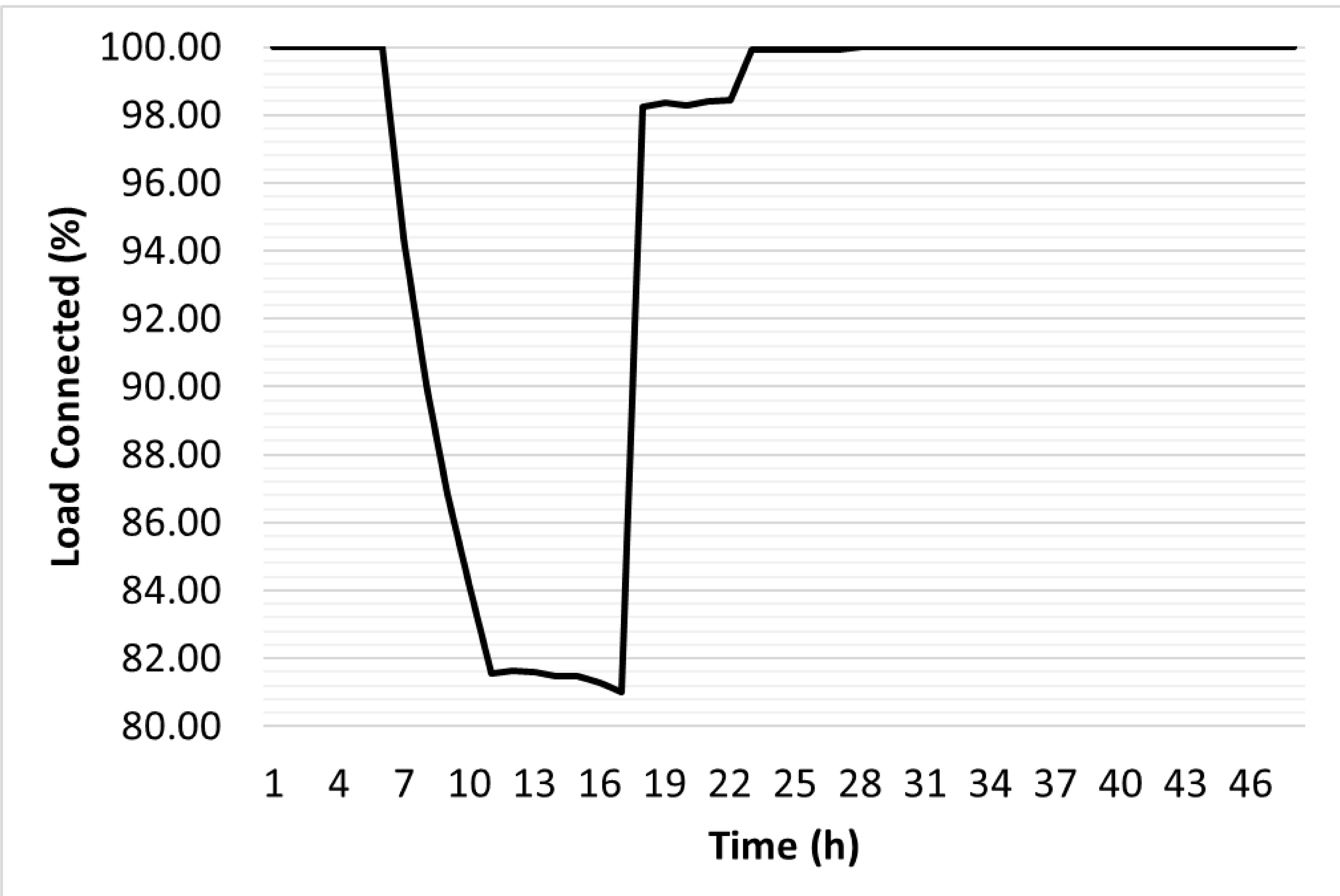


Figure 5. Resilience trapezoid of load connected (Case I)

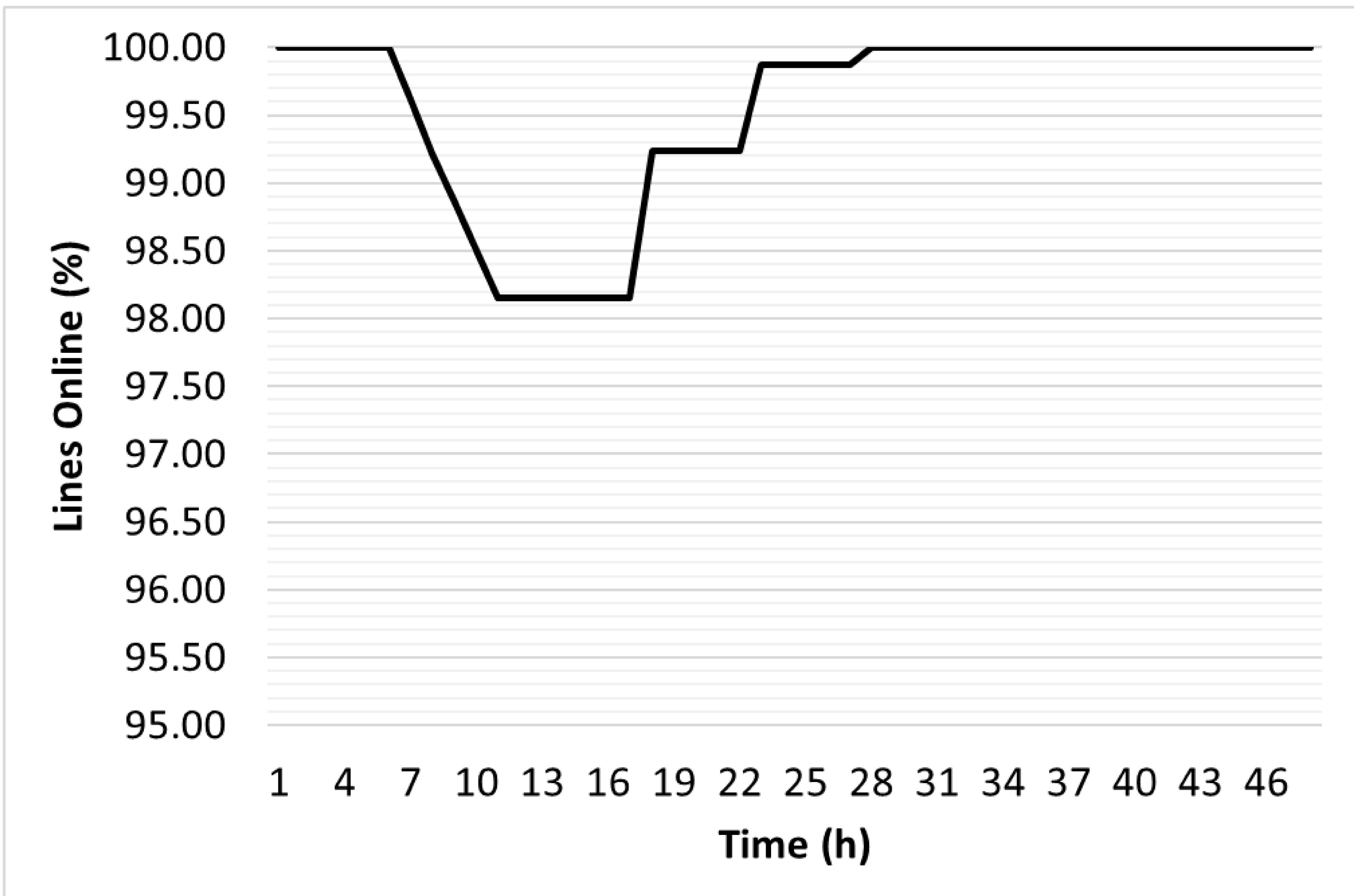


Figure 6. Resilience trapezoid of online lines (Case I)

Conclusion

- A methodology for assessing distribution system resilience and the generic structure of a tool supporting DSO decision making to improve system resilience is presented.
- The methodology described above is incorporated within the GRIDFLEX tool.
- Weather and network forecast data, can be combined and processed to warn the operator for the occurrence of extreme weather phenomenon, the arising risks for the network and the associated impact.