Techno-Economic Modelling and Assessment of Forward Resilience Measures

Dr. Eduardo Alejandro (Alex) Martínez Ceseña
Dr Mathaios Panteli
Prof Pierluigi Mancarella

The University of Manchester, Manchester, UK
Alex.MartinezCesena@manchester.ac.uk
Alex Martínez Ceseña – A bit about myself

• Academic Fellow – Multi-energy Systems

Research:
• Techno-economics, resilience and business cases
• Multi-energy and whole energy systems
• Integrated network planning
• Investment under uncertainty

Teaching:
Power System Analysis
Power System Operation and Economics
Increasing Uncertainty Levels
Increasing integration of distributed energy sources

Renewables:
- Low carbon
- Cheap
- \textbf{Inflexible}

Smart buildings:
- Flexible
- Controllable
- \textbf{Small and complex}
Increasingly integrated systems

It’s not only about electricity...

- Gas (34.3%)
- Coal (9.2%)
- Electricity (5%)
- Biofuels (2.2%)
- Petroleum (49.3%)
- Iron/Steel (1%)
- Industry (17.3%)
- Transport (56.7%)
- Domestic (48.5%)
- Other (18.4%)

© 2021 E. A. Martínez Ceseña – The University of Manchester
Increased threat of extreme weather events
Levels of uncertainty – Deterministic?

How do we see the future?

- Deterministic: There is a best-view future, and potential variations can be explored with sensitivity studies
Levels of uncertainty – Probabilistic?

How do we see the future?

- Probabilistic: There are multiple potential futures, which can be modelled with probabilistic functions
How do we see the future?

- Uncertain scenarios: There are multiple potential futures, it is not always possible to rank them or assign probabilities of occurrence

- Unknown: There is no consensus about how the future may look like
Levels of uncertainty – What does it mean?

\[ y = f(x) \]

\( x = \text{lost load or energy not supplied (ENS)} \)

\[ y = f(x) \]

\( x = \text{lost load or energy not supplied (ENS)} \)
Assessing System Resilience
Expected values

\[ y = f(x) \]

\[ \text{Mean} = \int_{0}^{D} x f(x) \, dx \]

\( x = \text{lost load or energy not supplied (ENS)} \)

\( y = \text{Probability} \)
Are expected values adequate for resilience studies?

The statistician who drowned while fording a river that was, on average, only three feet deep.

Conditional values

\[ y = f(x) \]

\( y = f(x) \)

\[ \text{CVaR} = \int_{Z}^{D} x f(x) \, dx \]

\[ A = \int_{Z}^{D} f(x) \, dx \]

\[ x = \text{lost load or energy not supplied (ENS)} \]

\[ Z \quad \text{CVaR} \quad D \]

\[ x = \text{lost load or energy not supplied (ENS)} \]

\[ Z \quad \text{CVaR} \quad D \]

\[ \text{(High Impact Low Probability events)} \]
Are Resilience and Reliability different?
the ability to limit the **extent**, **severity** and **duration** of **system degradation** following an **extreme event**.

- In CIGRE definitions, the generic term “**magnitude**” usually used in resilience definitions is replaced by the two terms “**extent and severity**”, which respectively refer to the **geographical extension** and the **intensity of the effects** of the event on the system.
- “**Severity**” in the present definition refers to the “**severity of the event consequences**”, which must be kept separate from the “**severity of the event**” which in general does not imply any system degradations.
- The term “**degradation**” is intended as “**deviation from specified target performances**”, both in system planning and operation as well as infrastructural and operational resilience.
- The term “**extreme event**” refers to high impact low probability (HILP) events, going beyond the “ordinary events” and referring to the “out of range type of contingencies” (ENTSO-E).

**Acknowledgments:** Emanuele Ciapessoni, Diego Cirio and Andrea Pitto, RSE, Italy
Resilience is achieved through *key actionable measures* to be *taken* before, during and after HILP, such as:

<table>
<thead>
<tr>
<th>Anticipation</th>
<th>Preparation</th>
<th>Absorption</th>
<th>Adaptation</th>
<th>Rapid recovery</th>
<th>Sustainment of critical system operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>• the process by which newly incorporated knowledge gained is used to foresee possible crises and disasters</td>
<td>• the process through which grid operators establish a set of actions to be deployed in case the critical operating condition occurs</td>
<td>• the process through which a set of measures is deployed to limit the extent, the severity and the slope of the degradation of power system performance</td>
<td>• the process through which changes are carried out in the power system management procedures, on the basis of past disruptions, in order to adjust the system to undesirable situations</td>
<td>• the process through which the energy supply to the customers is restored and the damages to the grid infrastructure are repaired</td>
<td>• the process which deploys the measures allowing an impaired power system to supply a minimum system load level in order to maintain a reduced but acceptable functioning of everyday life</td>
</tr>
</tbody>
</table>
FLEP Resilience Metric System

<table>
<thead>
<tr>
<th>Type of Actions</th>
<th>Time Sequence</th>
<th>Event hits the network</th>
<th>End of event</th>
<th>Restoration is initiated</th>
<th>End of restoration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preventive</td>
<td>Time $t_0$</td>
<td>$t_{oe}$</td>
<td>$t_{ee}$</td>
<td>$t_r$</td>
<td>$T$</td>
</tr>
<tr>
<td>Corrective</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emergency Coordination</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Restorative</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adaptive</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- $R_0$ represents the pre-disturbance resilient state.
- $R_{pd}$ represents the post-disturbance degraded state.
- $R_{tr}$ represents the restorative state.
- $T$ represents the post-restoration state.

The image shows the resilience trajectory over time, with distinct phases labeled as Phase I, Phase II, and Phase III, each representing different states of the network's resilience.
FLEP Resilience Metric System

<table>
<thead>
<tr>
<th>Time Sequence</th>
<th>Event hits the network</th>
<th>End of event</th>
<th>Restoration is initiated</th>
<th>End of restoration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Actions</td>
<td>Preventive</td>
<td>Corrective</td>
<td>Emergency Coordination</td>
<td>Restorative</td>
</tr>
</tbody>
</table>

- How fast resilience drops?
- How low resilience drops?
- How extensive is this state?
- How promptly does the network recover?
Techno-economic Modelling
Example – Modelling the impacts of HILP

Modelling the network

Modelling asset fragility

Modelling HILP impacts

Modelling HILP

Failure Risk
- 0.000 - 0.080
- 0.081 - 0.176
- 0.176 - 0.307
- 0.307 - 0.550
- 0.550 - 1.000
- 0.000 - 0.189
- 0.190 - 0.297
- 0.297 - 0.427
- 0.427 - 0.621
- 0.620 - 1.000

Max Wind Speed (m/s)
- 25.777 - 29.756
- 29.756 - 31.659
- 31.659 - 33.611
- 33.611 - 36.195
- 36.195 - 41.968

Modelling the network

Modelling HILP

Modelling asset fragility

Modelling HILP impacts
Example – Resilience assessment

Nodes
Transmission route – double circuit OHL
Transmission route – single circuit OHL

Highly Resilient
Less Resilient
Investing in stronger assets?
Investing in decentralised assets?

<table>
<thead>
<tr>
<th>Architecture</th>
<th>LCOE ($/KWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centralised</td>
<td>0.59</td>
</tr>
<tr>
<td>Decentr. – CVaR</td>
<td>0.42</td>
</tr>
<tr>
<td>Decentr - EENS</td>
<td>0.39</td>
</tr>
</tbody>
</table>
Investing in flexibility?

Flexibility might become more critical than redundancy in providing resilience to extreme events.
Concluding remarks

• We need to consider resilience as a means to face increasing uncertainties.
• Resilience metrics should address HILP and the conditions before, during and after the events.
• Investing in stronger assets, distributed resources and system flexibility are viable resilience measures.

Relevant projects:

• Forward Resilience Measures (Stage 1): [https://www.smarternetworks.org/project/nia_ngt0049](https://www.smarternetworks.org/project/nia_ngt0049)
funded by ESRC
• ATTEST: [https://attest-project.eu/](https://attest-project.eu/) funded by the EC
• FutureDAMS project: [http://www.futuredams.org/](http://www.futuredams.org/) funded by EPSRC