GROUP REF. : SC C1
COUNTRY : GERMANY
PREF. SUBJECT : PS 1
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QUESTION N° : 1.1.1

Assessing the Quantitative Resilience in Integrated Energy Systems

With this contribution, an answer to the Question 1.1.1 *Have others applied asset management tools and methods to set resilience measures or metrics?* should be given.
In the research project “ResiliEntEE – Resilience of integrated energy networks with a high share of renewable energies” at the Hamburg University of Technology, Integrated Energy Systems (IES) containing the sectors of the energy carriers electricity, gas and heat were assessed and analyzed. As most of the models in energy system analysis use optimization methods, the method of dynamic simulation was applied within the project “ResiliEntEE”. The dynamic simulation is based on component models from the freely-available TransiEnt Library, which was developed at the Hamburg University of Technology. This model library contains component models for the dynamic simulation of IES from the sectors electricity, gas and heat. Using dynamic simulation, the aspect of the security of supply can be considered more precisely compared to optimization methods. Hence, the topics of stability and resilience were on focus within the project “ResiliEntEE”. Resilience is defined as the energy system’s capability to withstand disturbances, maintain the supply task and recover from disturbances. The dynamic simulation was applied to the national IES of Germany with a focus on northern Germany. The national scale allows the verification of optimization models used for finding an optimal system configuration. All in all, future energy systems should feature low environmental impact, economic feasibility for the whole society and a high security of supply. Therefore, a holistic simulation and analysis approach including resilience assessment is necessary.

For evaluating the resilience in the project “ResiliEntEE”, results from the dynamic simulation should be used to calculate a quantitative measure for the resilience which is called Resilience Index (RI). Thus, the RI is calculated after the dynamic simulation has been performed. Based on the definition of resilience mentioned in the paragraph before and a literature review, three criteria are part of the resilience index. First of all, a critical variable must be chosen. This variable must be able to give insights into the system behavior. The choice of the critical variable can be discussed extensively. Either potential variables like the frequency of the electric grid or power flow variables like the gas enthalpy flow can be used for the calculating the RI. Based on the choice of the critical variable, a tolerance band is defined. For potential variables, a fixed tolerance band can be defined due to operation constraints. For power flow variables, which depict the supply task of the energy system, a time-variable tolerance band based on the time behavior in an undisturbed reference scenario is utilized. The first criterium is the Maximum Deviation which is the maximum deviation from the tolerance band Δx_{max}. The second criterium is the Recovery Time as the time outside of the tolerance band Δt. As the third criterium, the Performance Loss is considered as the area A outside of the tolerance band. All the measures are normalized by corresponding normalization parameters. The normalized measures are used to calculate the RI which is a number between 0 and 1. A RI of 0 means there is no resilience at all and a RI of 1 describes an energy system with complete resilience as the tolerance band is maintained for the critical variable. It is possible to assess more than one critical variable for the calculation of the RI, too. An overall RI is calculated using the weighted sum of single RI values. For weighting, the energy consumed in the regarded sectors or at the regarded component during the simulation time horizon is used. With those three criteria, the RI is comparable to measures from control theory like peak overshoot, settling time and a quadratic cots function for optimal control.

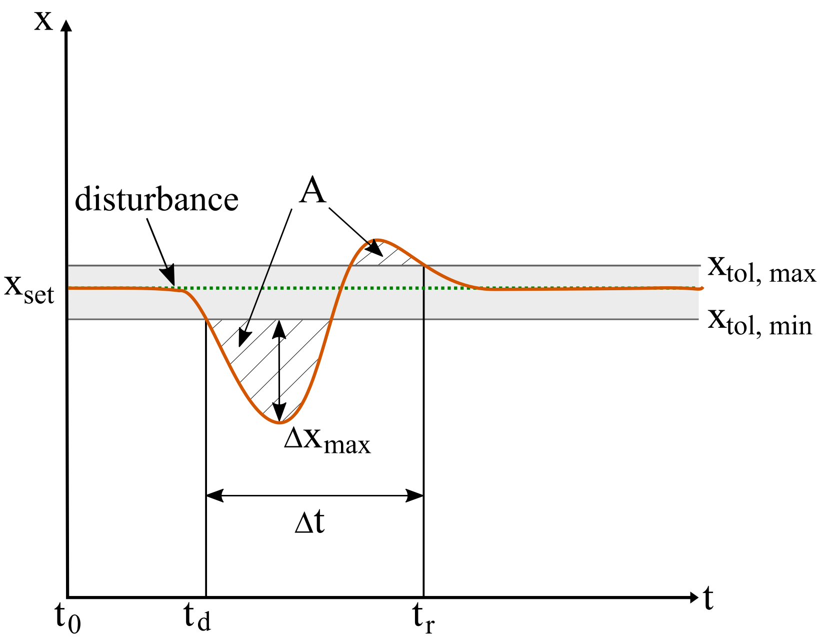

Figure 1 Criteria of the Resilience Index (RI)

The presented concept of the RI was applied on different system models. It can be demonstrated that the RI concept is able to assess the resilience of an energy system and it is especially applicable on IES. The results are highly dependent on the chosen normalization parameters. Thus, the RI must be regarded as a relative measure for comparing different configurations or scenarios of the considered energy systems. The results proof that the resilience enhancement strategies of storages, technology diversity and redundancy are appropriate because they lead to increased RI values in the sector the strategy is applied to. In contrast, the RI value for another sector can even decrease due to the applied system adaption. Consequently, changes and developments in energy system must be rated and the enhancements in one sector should be traded off against the risks for other sectors.

Further Literature:

- Resilience of Integrated Energy Networks with a High Share of Renewable Energies, Hamburg University of Technology, Final Report, C. Bode, J.-P. Heckel, O. Schülting, A. Senkel, C. Becker, A. Kather, G. Schmitz, Technische Informationsbibliothek, Hannover, 2021, doi: 10.2314/KXP:1794036792
- Quantification of the resilience of integrated energy systems using dynamic simulation, Reliability Engineering & System Safety, Band 209, A. Senkel, C. Bode, G. Schmitz, 2021, doi: 10.1016/j.ress.2021.107447
- Using Modelica to Assess the Resilience of a Heat Supply System, In: Proceedings of Building Simulation 2019: 16th Conference of IBPSA, Rome, Italy, September 2-4 2019, Senkel, A., Schmitz, G., pp. 1941-1947, ISBN: 978-1-7750520-1-2
- Evaluating the Resilience of Energy Supply Systems at the Example of a Single Family Dwelling Heating System, Proceedings of the 13th International Modelica Conference, A. Senkel, C. Bode, G. Schmitz, Regensburg, 2019, doi: 10.3384/ecp19157655
- Dynamic Simulation of an Integrated Energy System for Northern Germany with Improved Resilience, Proceedings of the Inernational ETG Congress 2019, J.-P. Heckel, C. Becker, Esslingen am Neckar, 2019