D6.2 TECHNICAL REPLICATION ANALYSIS FOR A FULL ROLLOUT OF THE ANM4L SOLUTION

VERSION 1.0

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TABLE OF CONTENT

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Co-creating with partners that help to understand the needs of relevant stakeholders, we team up with intermediaries to provide an innovation eco-system supporting consortia for research, innovation, technical development, piloting and demonstration activities. These co-operations pave the way towards implementation in real-life environments and market introduction.

Beyond that, ERA-Net SES provides a Knowledge Community, involving key demo projects and experts from all over Europe, to facilitate learning between projects and programs from the local level up to the European level.

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INTRODUCTION TO ANM4L

The ANM4L (Active network management for all) project, anm4l.eu, will develop solutions to enable integration of renewables with the agility required from developments in demand and production.

Alternatives to traditional network expansion are needed to ensure sustainable development of the power grids. New technologies, methods, and markets are emerging to provide increased flexibility in consumption, generation, and power transfer capacity.

ANM4L aims at demonstrating innovative active network management (ANM) solutions to increase integration of renewable energy sources (RES) in electricity distribution systems.

ANM solutions will consider management of active and reactive power to avoid overload situations, maintain voltages within limits, minimize the need of RES curtailment, and enable further RES uptake even above the theoretical design limit of the electricity network.

Core research and development activities include development of:

- Active network management methods for local energy systems.
- Business models to provide decision support for market players.
- An integrated toolbox to support the planning and operation of the distribution system.

The toolbox, methods and business models for ANM will be demonstrated in Sweden and Hungary. The project will also prepare solutions and recommendations for replication in other local and regional energy systems.

The ANM4L project is an international cooperation with a consortium consisting of partners in Sweden, Germany and Hungary:

- RISE Research Institutes of Sweden (coordinator)
- Municipality of Borgholm
- Lumenaza GmbH
- Lund University
- RWTH Aachen University
- E.ON Energidistribution AB
- E.ON Észak-dunántúli Áramhálózati Zrt.
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DOCUMENT INFORMATION

This document provides a technical analysis of the replication process of ANM solutions developed in the ANM4L project.
The task deals with developing the business models and replication plans for a grid different from the demonstration sites. It starts by extracting the output from the results of the demonstrations then preparing and performing the effective replication in other regions.

The end goal is to give technical recommendations for the replication to additional locations and to identify possible limitations. In particular, it was investigated if the developed solutions are interoperable, flexible and adaptable to other use cases.

1 DEFINITIONS AND ABREVIATIONS:

ANM4L: Active Network Management for all (project name)

ANM: (Active Network Management): is the exploitation of flexible network assets for the purpose of providing secure means of increasing grid utilisation.

ANM solution: is the concept of a control system, integrated with ICT and the power system, with the ability to manage generation, load and electrical tolerances for DSO-driven purposes.

Flexible network assets: assets in the grid (load, production, and other controllable equipment) with the ability of being controlled to support grid needs.

ICT: Information and Communication Technology

RES: Renewable Energy Sources

DER: Distributed Energy Resources

API: Application Programming Interface

REST API: Representational State Transfer API.

CBA: Cost Benefit Analysis

BAU: business-as-usual

2 CONTEXT AND INTRODUCTION

One of the main objectives of the ANM4L project is to develop an interoperable toolbox for ANM solutions, which can be fully or partially adopted by any of the 2400 European DSOs for secure planning and operation of their respective LV and MV grids.

In the first development cycle, the project developed methods, business models and ICT tools from a generic perspective, having in mind the replicability requirements. The validity and value of the developed generic solutions was demonstrated through field trials in Sweden and Hungary. The demonstrations served to finalize the second development cycle by adjusting the generic solutions to local constraints, monitoring the implementation, and deriving recommendations for replication.

Finally, a full replication for a site in Hungary different from the demo site location was performed. This concluded the final development cycle of the toolbox with new methodologies for the assessment of replication and scaling up potential.

The current document describes the technical aspects of the replication process of the ANM toolbox. First an overview about the main building blocks of the ANM planning and operational tools is given. Next, the technical analysis from the replication of the tools is performed, by focusing on assessing whether the interoperability requirements are met and identifying the limitations for replicability. In addition, a brief summary of survey results about the DSO planning needs regarding grid investments is given. Finally, the most important conclusions and recommendations for replication are emphasised.

3 ANM TOOLBOX COMPONENTS:

The project developed modular generic software solutions in form of tools, methods and business models that can be applied by DSOs to operate mid- and low voltage distribution networks without violating their voltage and current limits. The motivation behind the generic aspect of the solutions make them easily replicable, scalable and adaptable to new use cases.

ANM solutions are the concept of a control system, integrated with ICT and the power system, with the ability to manage generation, load and electrical tolerances for DSO-driven purposes [1]. The primary goal of applying ANM solution is to avoid grid reinforcements measure that might arise due to capacity and voltage problems [1]. Such solutions offer powerful alternatives to grid extension measures especially in dealing with the increasing number of RES connections to the distribution system.

The developed ANM solutions that form the main building blocks of the toolbox are:

ANM methods: algorithms for active and reactive power control to perform grid congestion management and voltage limitation.

ANM ICT system: tailored interface in form of REST APIs to ensure the proper communication between the hardware and software modules.

ANM business models: analysis to assess the cost effectiveness and value of ANM solutions, compared to conventional approaches such as grid reinvestments and reinforcements.

We start by giving an overview and a description about the most important aspect of each module.

3.1 ANM methods

The core module of the ANM solutions are the ANM methods. The methods are a set of algorithms developed within the project to control active and reactive power of flexible assets within the distribution network. The control measures serve to mitigate overvoltage and overloading of network components. The algorithms are derived from a basic structure, which includes a PI controller and an input signal that is computed from limit values rather than a reference value. This makes it possible to safely operate the network within voltage and current limits [3]. The main objective of the ANM algorithms within the scope of ANM4L was to have control schemes that are: easily deployable, scalable and adaptable to different network topologies. The motivation behind favouring simplicity over optimality was to allow the replicability of the methods by other DSOs for different use cases. A detailed description of the types, structures, functionalities and use cases of ANM algorithms can be found in [3].

The algorithms were initially embedded through Python scripting in a commercial power system simulation software for testing. To increase the availability and the interaction capability with external tools, the Python scripts were combined to form a Python package to be used as a library in power system simulation.

3.2 ICT system

To meet the Interoperability and replicability requirements of the ANM solutions, the focus should be on services rather than platforms or technology stacks. The advantage of this approach is that the same service can be provided by different platforms. Hence, a deeper integration does not necessarily require the use of the same platform. Focusing on the services enables a faster transition than trying to move all partners to a specific platform [2].

The services-approach requires a robust and secure ICT system, which establishes the communication channels between the ANM solutions developed within the project and also to external hardware and software solutions. The basic technology for such an ICT system are Application Programming Interface (APIs). To provide access to a service, the user only requires a specification of its API. The source code implementing the service is not required [2].

3.3 ANM business models

To assess the financial and economic impact of flexibilities for utilities, the project developed a tool for Cost Benefit Analysis (CBA) [4]. The CBA tool is a framework that can be used to evaluate investment options available at the disposal of the DSO. The CBA can be employed for two different use cases:

- Assess if one investment option should be made
- Compare different investment options to each other

In the context of ANM4L, the CBA deals with evaluating the traditional solution of investing in physical infrastructure to increase the network capacity and the alternative solution of using local flexible assets to control the flow of energy and optimally use the network capacity [4]. The two use cases mentioned above are considered. In the first case, the evaluation is done by comparing each investment option to a business-as-usual (BAU) scenario, where no investments are made. In the second case, the two investment options are directly compared against each other.

Furthermore, the cases can be compared from a DSO perspective (financial CBA) as well as a societal perspective (economic CBA). The financial CBA evaluates if the benefits outweigh the costs for the DSO, whereas the economic CBA evaluate if the benefits outweigh the costs for the entire society [4].

4 TECHNICAL REPLICATION ANALYSIS

The methods, the ICT system and the business models were combined and extended with external tools. The aim is to have a system that will ensure the interoperability and replicability requirements by allowing the use of existing data and existing software. The toolbox is formed by the following two global tools:

- Planning tool to assess the technical and financial impact of ANM solutions with two main use cases:
    - Technical analysis: active and reactive power control scenarios for voltage limitation and congestion management planning
    - Financial analysis: cost benefit analysis for assessing alternative scenarios compared to reinforcement and reinvestment scenarios.
- Operational tool to help the network operators to estimate the status of the grid and the available ANM grid assets to use in order to maintain a secure operation of the grid. In addition, the tool implements a market solution in form of a graphical user interface for flexibility offering.

The previously mentioned tools are the one demonstrated in the field trials and replicated for the replication site. In the next section, we start the technical replication analysis by giving an overview about the general strategy and steps adopted to replicate the toolbox to further locations and use cases, followed by the specific technical analysis for each tool.

4.1 Replication process

For the full rollout of the ANM planning and operational tools in the Hungarian replication site, a general replication strategy was first adopted. It can be applied to both tools and transferred to future developments. The replication was performed according to the following generic steps:

Step 1: Need & Site identification:

In general, identifying the need for an ANM solution comes from the experiences and the observations of the DSO. The needs are closely related to the locations; since capacity and grid issues in radial LV and MV grids are local phenomena that are caused locally and that can be solved locally with ANM solutions. The following considerations are helpful for need and site identification:

- Reoccurring congestion or voltage violation in a location of the radial MV/LV grid. In this regard, historical measurements as well as simulation models help to identify the need and locations of the grid, where an ANM solution is advantageous.

- High shares of RES or single RES units with big impact that can be used to manage grid issues.
- Increasing requests for new generation connections in a location with limited capacity, which might lead to grid capacity issues.
- Financial regulatory incentives to use the high shares of RES units to avoid grid reinvestment or reinforcement measures. In this case, business models are a useful tool to compare the financial advantages of ANM solutions compared to traditional measures.

Step 2: Data preparation:

In this step, the data that are required by the ANM solutions are prepared. The data can contain historical measurements, simulation models of the identified site as well as real time measurements from the DSO SCADA system. The aim of this step is to have a data set that can deliver a realistic assessment of the grid state to the ANM solutions. The accuracy of the data is of great importance, because it affects the fidelity of the end results.

Step 3: Data adaptation

The data adaptation process converts the data to the format required by the ANM tools or extends it with additional technical or regulatory data relative to the DSO, the country and the use case.

Step 4: Implementation

In the implementation step, the different software and hardware components of the ANM tools are brought together to form the desired solution. The core task of this step is the implementation of scripts and/or communication channels of the ICT system preferably in form of REST APIs. REST APIs are the preferred way to implement the communication between web-based application because of their simplicity, flexibility and speed.

Step 5: Testing and evaluation

In this step, the validity of the implemented solution is investigated. Testing is performed by running the tools and evaluating the results of each tool and if possible comparing to third-party tools for validation.

Step 6: Deployment in DSO environment:

Bringing software and hardware components that are developed by several parties is a challenging task. Especially the deployment of solutions that are developed outside the DSO environment might be critical to the DSO IT system. If they are to be integrated in the DSO IT environment, a secure, sustainable solution should be applied. In this regard, the containerization of the applications has the potential to isolate the external applications from the internal one, therefore reducing the dependencies to the DSO IT system and increasing the security.

The above listed replication steps are a general guide to replicate any of the ANM4L solutions. In praxis, depending on the Tool to be replicated (planning or operational), the process for each step is different. This will be looked at in more details in the next sections.

4.2 Replication of the planning tool

An overview about the planning tool building software modules and external DSO dependencies is depicted in figure 1.

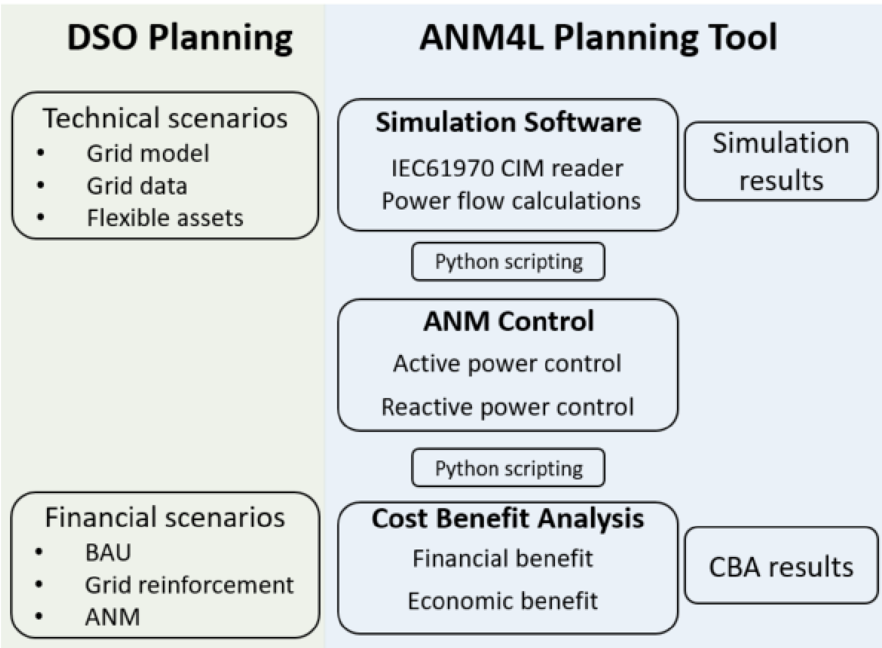

Figure 1: Panning tool building blocks and external DSO dependencies

The starting point of a technical analysis are the technical scenarios. Such scenarios define the system topology and ratings of component for the considered grid (grid model). In addition, the profiles for the generators and loads (grid data) are an essential input to allow continuous power flow calculations in the simulation software. The grid model and grid data are necessary input data to the simulation software. The input data to the ANM control are the available flexibilities in the grid along with their technical characteristics (e.g. flex. ranking, flex. rate of change of power, flex. sensitivity factors etc...). In addition, the capacity of lines and transformers as well as the specific bus voltage limits and branches to monitor for congestion are given.

An important module for the technical scenarios of the planning tool is the power system simulation software. The simulation software should reflect the real world power system through the grid model and state through the grid data of the chosen location. The implementation of the ANM control algorithms is based on iterated power flow calculations, which requires a stepwise interaction between the ANM tool and the surrounding simulation environment. A major advantage of this design is that only minimal alterations of existing network models in external simulation software (i.e. no changes of existing dynamic generator or control models) are needed, as all required computations are shifted to the ANM control, which will simply provide updated set points for relevant flexibility assets. The data exchange between the ANM control is performed through Python scripting. The choice of Python programming language is mainly motivated by the fact that the ANM control is written in Python and the open source simulator (*DPsim*) and commercial simulator (*DIgSILENT Powerfactory*) used in the project allow for external interaction with the simulation through Python interfacing. Python is also an easy to learn script language.

In the simulation software, the power flow calculation of the network is run continuously and initialized in each simulation step with the profile values of load and generation from the grid data. In each iteration, the ANM control requests the power flow computation from the simulation software for the day and time of interest. The ANM tool retrieves the power flow results, as well as separately stored additional data from the technical scenario, which as mentioned above include technical parameters about the available flexibility assets and updated network operational limits. In case a congestion or a voltage limit violation is reflected by the power flow results, a control measure is triggered. This means that new active and reactive power set points, different from the profile values, are computed for the flexibilities and then used to update the simulated network model. By assigning the control values to the flexible assets and running the next power flow iteration, the congestion or voltage violation problem is solved. The power flow results from the new set points of flexibility assets are stored for analysis and visualization. The resolution (study time) of the power flow is updated according to the pre-set ANM controller sampling interval.

For the financial analysis, the financial scenarios provide the scope and input data to the CBA tool. The financial scenarios include the costs and revenues/benefits of different cases for which a CBA will be calculated. The revenues follow usually a regulatory model, which might differ from country to country. The costs include the investment costs, the value of the connections, the energy losses, the operational costs and other externalities such as visual impact. A BAU case describes the situation where no additional investment in the grid is made by the DSO. The grid reinforcement case describes the situation for a traditional investment such as extending the network with a MV overhead line. The ANM case is the alternative to the traditional investments. It is the situation of using flexibilities to increase the network capacity and avoid extending the network. The CBA results reflect the comparison of NPV of the different CBAs both financially and economically.

A detailed analysis of the replication strategy of the planning tool is given in Table 1. The table gives for each replication step the technical aspects that are considered and are recommended to meet the requirements for replicability and interoperability of ANM solutions for planning purposes.

Replication step	Replicability and interoperability analysis
Step 1: Need & Site identification	- Identification of a site that satisfies the general requirements described in 4.1 and with an already available grid model and grid data. - Identification of possible flexible assets in the grid model.
Step 2: Data preparation	- Preparation of a standardized data format for the grid model, which is supported by most open source and commercial simulators. The IEC 61970 CIM standard is the preferred choice since it is becoming more and more adapted by TSO/DSO. CIM facilitates the model transfer between simulators as well as the network data exchange between network operators. - Preparation of grid data in the form of load and generation profiles for all the generators and loads in the grid model. - Preparation of the data for identified flexibilities: flexibilities ranking, flexibilities rate of change of power, flexibilities sensitivity factors. - Preparation of costs (purchasing, constructing, installing and testing) and benefits (revenues and tariffs) of the different financial scenarios (BAU, grid reinforcement, ANM) - The BAU case should not be seen as a possible option for the DSO since it is in most of the cases legally not possible to decline connection of new RES generation. It is exclusively used to compare the two other cases against a current state where it is assumed that no investments are made.
Step 3: Data adaptation	- In most of the cases, historical measurements are used as profiles for power flow calculations. These profiles describe the actual load and generation behaviour for a given season, day and time. However, most of the time, the historical measurements cannot be directly mapped to the grid model for the power flow simulation because the simulation does not model every single generation and consumption measured in the grid. In this case, the measurements should be aggregated to be aligned with the generation and load substations of the grid models. - The input to the CBA tool should be extended with the regulatory model that governs the DSOs tariffs or revenues of the country in question and incorporated into the tool.
Step 4: Implementation	- Having an open source simulation software with an already implemented interface to the ANM control as part of the tool is of great advantage. It gives the possibility to test the planning tool with free software and without the need to pursue a licence. This can serve as an initiation for DSOs to simulate ANM algorithms and have an assessment about their value. Once the decision is

Replication step	Replicability and interoperability analysis
	met to use the ANM algorithms on the long term the transition to third-party commercial simulation software, if desired by the DSO, can be easily done by modifying the interface. - Interfacing the modules of the tool by Python scripting is advantageous. This offers the possibility of easy adaptation and maintenance of the tool. For instance, if the DSO change the simulation software, only the scripting interface to the ANM control algorithms is to be modified. - Python programming language is preferred because it is easy to learn, use and understand. In addition, most of the open source and commercial simulation software allow for external user interaction through Python scripting.
Step 5: Testing and evaluation	- The integration of the simulation software with the ANM control module should be tested against an already integrated simulation software for validation. This will give a first indication for the correct implementation of the interfacing Python script. - The accuracy of the overall simulation environment can be validated and tuned with measurements from the real grid.
Step 6: Deployment in DSO environment	- Ensure the safety and proper function of Docker containers in the DSO IT infrastructure.

Table 1: Technical analysis for the replicability and interoperability of the planning tool.

4.3 Replication of the operational tool

An overview about the generic architecture for the building software and hardware modules of the operational tool as well as the external DSO dependencies is depicted in figure 2.

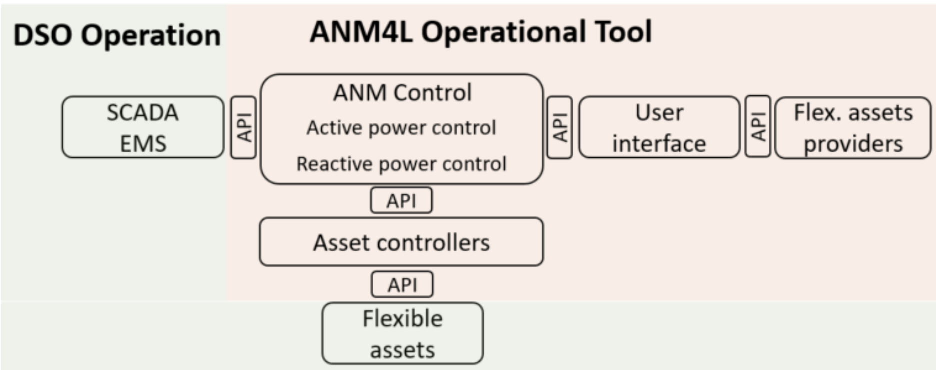

Figure 2: Operational tool building blocks and external DSO dependencies

The operational tool connects DSO, ANM control, flexible assets and possible flexibility providers. In contrast to the planning tool, the control interacts with real world assets instead of a simulation model. The implemented APIs are tailored interfaces to ensure the proper communication between the hardware and software modules of the real world system.

The implemented ICT system communication channels are:

- API for establishing the communication channel between the controller and the asset.
- API for establishing the communication channel between the controller and the ANM control.
- API for establishing the communication between the ANM control and Flexibility user interface.
- API for establishing the communication between the User Interface and flexible assets providers.

When the ANM Python package is used in operation, there is no power system simulation involved. Instead, the ANM control retrieves measurements from real grid assets and returns control set points. This shift of the location of control operations, while preferable in a simulation environment, differs from how the algorithms would be deployed in a real-world implementation. ANM controllers would be distributed on the DSO network at flexible asset locations. The controllers would typically compute the change from a current operational point, and the set point change would then be executed by the asset controller. This difference in implementation, however, does not affect the underlying structure of the algorithms or the outcomes from their use in the different environments.

Furthermore, the additional user interface is used as a demonstration platform for flexibility providers to offer their flexible assets and fix limits for the control of active and reactive power curtailment. The user interface implements also a virtual remuneration scheme to compensate the providers for the power curtailment.

Similar to the planning tool, the following table gives a detailed analysis of the replication strategy of the operational tool with the major replicability and interoperability aspects.

Replication step	Replicability and interoperability analysis
Step 1: Need & Site identification	- Identification of a site that satisfies the general requirements described in 4.1 and with already installed measurement units to the flexible assets. The measurements are preferably visible in the SCADA/EMS system of the DSO. - Identification of flexible assets from the selected site.
Step 2: Data preparation	- The time interval of measurement collection in the SCADA/EMS system has to be in the timescale of the asset

	controller sampling interval or less in order to ensure live assessment of the control procedure.
Step 3: Data adaptation	- Data encryption is important if the data are intended to be exchanged between different parties.
Step 4: Implementation	- Implementation of lightweight replicable communication mechanisms is conducted with REST APIs to establish bi-directional communication channels between different systems. - Installing a controller with a built in internal metering and control logics using cheap hardware and open source software. - The implementation of a user interface helps to test and evaluate end-user (flexibility providers) interaction and experience, for a flexibility market solution. - Cheap off-the-shelf hardware together with open source tools allow the development of a robust ANM ICT Toolbox, which is easily reproducible.
Step 5: Testing and evaluation	- In the testing phase, the changes of active and reactive power of the flexible assets should be limited to ensure the safe operation of the controlled hardware. After several trials, the limits can be changed to use the full control range of the asset.
Step 6: Deployment in DSO environment	- Ensure the safety and proper function of the API interface to the SCADA/EMS system of the DSO. - Only expose endpoints of the APIs and ensure that all API communication is encrypted.

Table 2: Technical analysis for the replicability and interoperability of the operational tool

5 DSO SURVEY

In the last phase of the project, a survey was designed and addressed to European DSOs about their need for an ANM planning tool. The survey focused on the planning tool by investigating the need for a toolbox that could support the decision process regarding grid investments. The survey results from DSOs in Germany, Sweden, Czech Republic and Hungary shows an interest in using a tool for supporting planning, where some of the main use cases for this include enabling faster connection of production or load, environmental/social constraints for new lines and decreased need for capital investments. Blockers for implementing this kind of toolbox include both internal factors such as manual decision-making processes as well as external factors such as regulatory environment.

6 CONCLUSION

This deliverable summarizes the technical aspects to consider for a full replication of the ANM4L Toolbox. The aim is to give a strategy and relevant technical considerations and recommendations to meet the interoperability requirements. This will ensure a smooth replication and adaptation of the toolbox for planning and operation of radial low and mid voltage distribution grids. As part of the technical analysis, an overview about the developed tools is given along with the detailed strategy for the successful replication process of each tool.

The most important technical replication and interoperability requirement is the concept of the overall architecture of the solutions in form of independent processes. Each process is performing a dedicated task and can interact with auxiliary software and hardware modules via lightweight communication mechanisms using REST API interfaces.

In summary, the modularity of the ANM solutions facilitates the replication of the ANM Toolbox in new environments. Furthermore, the tools are flexible since they implement decoupled modules. Therefore, it is not necessary to have a full roll out of the solutions to have a functioning system. Single services can be implemented, adapted and extended according to the needs and requirements of the DSOs. It is shown that the overall ANM4L solutions can move beyond the project partners and field trials to allow a full roll-out of the developed services outside the scope of the project.

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