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Published in:
2024 IEEE International Conference on Communications, Control, and Computing Technologies for Smart Grids (SmartGridComm)

DOI (link to publication from Publisher):
10.1109/SmartGridComm60555.2024.10738050

Publication date:
2024

Document Version
Accepted author manuscript, peer reviewed version

Reliable electricity distribution using a digital twin based on explainable artificial intelligence

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***Abstract*—In this short paper we present the project Reliable Electricity Distribution utilizing a Digital Twin based on eXplainable Artificial Intelligence (ReDistXAI). Target of the project is to successfully apply methods of explainable Artificial Intelligence (XAI) for the detection of input data anomalies for the digital twin of the electricity distribution grid. As a second use, the detection and localization of grid faults via XAI approaches will be assessed. The paper explains the two use-cases and elaborates the benefits and challenges when applying XAI methods in the form of Bayesian networks to these use-cases.**

I. Introduction and background

Digital Twins are an upcoming key instrument for Distribution System Operators (DSOs) to resolve some of the current and future challenges in distribution grids. Monitoring and use of smart meter data for grid observability already enabled a range of smart grid applications e.g. in RemoteGRID, [1] and use of multiple heterogeneous measurement data sources in conjunction with smart meter data in Net2DG, [2].

Figure 1 shows the generic concept of using a digital twin as a 'live' copy of the real physical world, which uses incoming streams of measurements together with automatically updated grid structural information in order to automatically derive an parameterized grid model that is accurately representing the true electrical state of the grid and the behavior of loads and generators. The inferred historic and current state of the grid and connected assets is then used in automated applications to perform DSO specific operations ranging from grid monitoring, grid planning, maintenance, and automated control of flexibilities of grid assets.

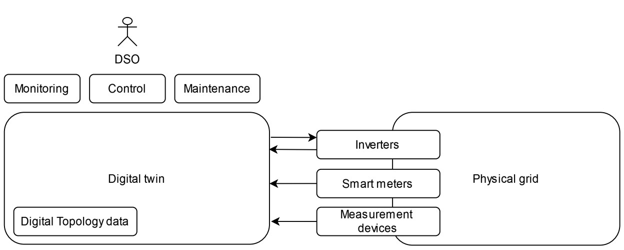

Fig. 1. Digital Twin concept

In the Net2DG project [3] this concept was demonstrated in two specific field tests, where smart meters from a field test where combined with measurements from inverters and with substation measurements. The automatically derived model was subsequently shown to allow detection of bottlenecks and voltage violations [4], to successfully use the physical grid capacity for PV connections [5], and to enable fault localization for outages in Low-voltage grids [3] as well as for Earth-faults in compensated Medium voltage grids [6]. Experiences from these field tests and a subsequent number of commercial deployments of the Digital Twin in Germany and Austria were that digital input data is far from perfect, and large efforts on dealing with data quality, such as wrong trafo parameters, wrong measurement transformer values, missing data or incorrect topology information was causing effort and delays. In order to scale the digital twin for large deployments automated methods for input data quality detection are required and being researched.

The above input data anomalies manifest themselves by a deviation of a subset of the observations from the true physical grid behavior. A similar deviation can on the other hand additionally result from grid faults, i.e. when the true physical behavior of the grid deviates from the desired one, e.g. due to short-circuits, earth-faults, or due to high harmonic distortion caused by the erratic behavior of a grid connected inverter. Detection and localisation time is critical for the DSO.

However, the detection of input-data anomalies and the detection and localisation of grid faults based on the digital twin are complex and interlinked, so the use of data-driven approaches with artificial intelligence (AI) is promising. In order to account for the criticality of the underlying infrastructure, explainable AI methods may show higher end-user acceptance than black-box machine learning algorithms. Therefore, this project will investigate the use of explainable AI to effectively address input data anomalies and grid fault-localization using a digital twin of the distribution grid.

II. Use cases and scope of project

The selected use cases are chosen such they address key challenges that DSO's are experiencing.

A. Data quality

Data in smart grids are manifold by the way it includes 1) measurement data from various points in the grid which changes on a minute to quarterly scale, and may suffer from not always be synchronized or data may be missing or in other way corrupt or inaccurate. 2) Grid topology which changes more rarely, e.g. in conjunction with switching equipment or faults. 3) Parameters for cables and grid equipment in the grid are usually outdated by many years and/or simple data sheets are used for grid calculation. Improving data quality and removing wrong or missing information impacts grid calculations leads to increased performance of e.g. fault localization.

B. Fault localization

A critical element in a DSO responsibility is to ensure voltage at end customer at all time. While faults do happen, it is critical that the time spend on detecting, localizing and repairing faults are kept at a minimum. The localization is in particular challenging as faults manifests themselves in many ways, and determine cause of a fault may be related to time consuming false-positives or false-negatives. So it is in the interest of the DSO to minimize the risk of getting false-positives/negatives while maximizing the probability of getting positives in detecting fault causes and localize these accurately. By doing so, the time from fault to repair is expected to significantly be reduced.

III. Technical concept and system approach

A. Explainable AI Method

ReDistXAI applies Bayesian networks (BN) as the methodology to implement XAI in the Digital Twin as they support transparency and explainability, which make them well suited for the use-cases. The BNs for data quality and fault localization are estimated from consumption and signatures profile time-series data, respectively, using expert knowledge in the construction and interpretation of the models. Models are developed iteratively as data sources are identified.

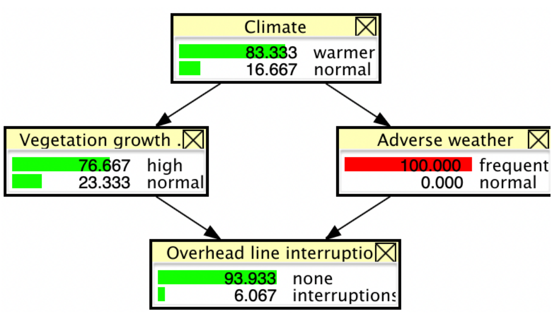

Fig. 2. Bayesian network example [7]

Figure 2 shows an example of a toy BN (with evidence on frequent adverse weather) applied to distribution system maintenance management taken from [7]. Similarly, [8] apply machine learning for predicting voltage sag. The benefit of using BN in addition to the explainability is the seamless integration of the data from different sources and expert knowledge [9]. This feature is exploited in ReDistXAI to cope with the level of uncertainty in data and knowledge.

B. Solution Architecture

The high level architecture is sketched in Figure 3 and consists of a Data Fusion Hub, use case related modules, and the XAI engine responsible for delivering explainable AI using BNs for the two use cases. The Data Fusion Hub (DFH) enables a uniform data access to sources and provides the Digital Twin functionality. The responsibility of the DFH is to ensure access to data with different interfaces, normalize data, interaction patterns, security associations and data formats.

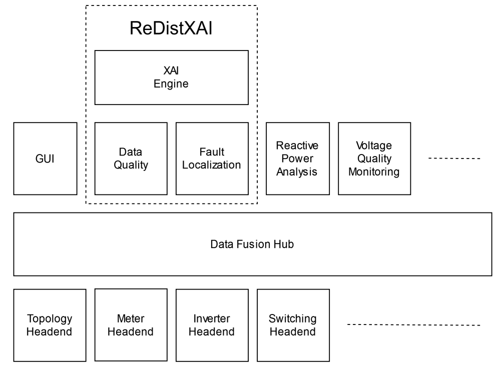

Fig. 3. ReDistXAI concept centered around two modules utilizing a Data Fusion Hub

Two of many modules, here Data Quality and Fault Localization, are central to the aforementioned use cases that relies on the DFH, as shown in Figure 3.

IV. Summary and Outlook

Within the project period of three years, the target is to demonstrate the efficiency of the XAI approach to enable data quality and fault localization use cases.

Acknowledgements

This work has received funding from the Eurostar project ReDistXAI, grant no. 4748.

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