How to overcome difficulties met in deploying digital twins of electrical assets over their whole life cycle? A data management perspective

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Abstract

There is an increasing interest from Utilities or electro-intensive electricity users to use the digital representation of electrical assets, i.e., “digital twins”, with the aim of increased life span, decreased operation cost and increase operation safety. The reality is that such ambition faces many difficulties for real industrial deployment, especially by lack of data or lack of data interoperability. This paper will first assess the usage of digital twins in this context, identify main difficulties, then derive requirements applying to the data and the data processes. Then the paper will assess technics which may overcome these difficulties and meet the above requirements.

1. Introduction

There is an increasing interest from Utilities or electro-intensive electricity users to use the digital representation of electrical products, systems and assets.

Such digital representations aim at inheriting the benefits of software paradigm namely flexibility, configurability, re-usability, specialization, upgradation and troubleshooting to improve the usage of the considered asset.

1.1. Main concepts description and definitions

1.1.1. Digital twin: According to [1], who co-edited an ERCIM special issue on Digital Twins[9], a digital twin is “a digital replica of real-world devices, processes or even persons”.

Usages of digital twins in cyber-physical systems vary from modelling and simulating the infrastructure (digital model) to providing real-time information from the physical space for performance analysis (shadowing), as well as for maintenance and monitoring of the physical asset.

In some more advanced case, the digital twin complements the features of its physical counterpart and becomes active alongside its physical counterpart [2]. Physically connected at the infrastructure edge (closer to the connected objects), digital twins are designed in the way they progressively become “intelligent digital twins” [3] that involve learning and autonomy.

In the power sector, usage of digital twins vary from wind farm modelling [3], to the application of the concept of digital twin with IoT technology to the operation and control of the electricity distribution system for simulation and data analysis [4]), to real-time power flow analysis, based on data-driven and real-time integration between digital and physical spaces [5], to power systems controllers or distributed energy management system [4].

There are possibly many digital twins of the same asset, established for different purposes to serve different stakeholders. These twins may not be the exclusive one to each other.

For each of these possible applications, there may be different levels of faithfulness (very fuzzy behaviour versus very accurate behaviour emulation) /levels of depth (very high-level synthesis versus very detailed monitoring of all properties) in reflecting the asset itself.

1.1.2. Digital thread is defined in [6] as a way to link together all the information generated from every stage of the product lifecycle through a data-driven architecture of shared resources (refer to Figure 1).

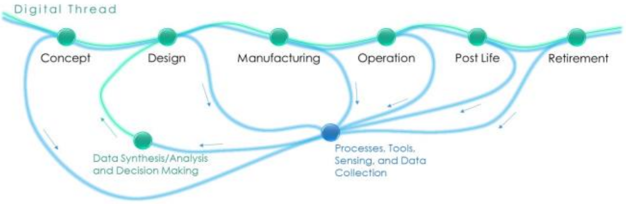

Figure 1 Digital thread

These resources can include various tools, methods, processes, storage, and even real-time data captured from sensors. Digital Threads can become a primary source of information to create and update digital twins.

A digital thread can be created for many different entities and processes. Most commonly, a thread of a product follows the lifecycle from design inception through engineering and product lifecycle management, to manufacturing instructions, supply chain management, and through to service histories and customer events.

To achieve a digital twin, a digital thread must first be established. Digital thread is predominantly used to unify and orchestrate data across the lifecycle of a product, from original design, to engineering, manufacturing, operation, and service.

1.1.3. Our definition of "digital twin": A digital twin is any digital and possibly partial replica of real-world functions, devices, processes or even persons.

1.2. General classification of digital twins.

Different types of digital twins are defined in [3] based on their level of maturity. However, this document wants to go beyond this view and to complete it in an attempt to merge both the academic and industrial view. The result is exposed in Table 1.

Table 1 - Typical types of digital twins

Type	Description
Static twin	A static list of digital properties of future or current asset.
Functional twin	Static twin plus some dynamic behaviour capabilities of future or current asset.
Adaptive digital twin	Functional twin supporting dynamically changing capabilities and acquisition of data
Intelligent digital twin	Adaptative twin plus autonomy, learning, reasoning, acting capabilities in regards to system level test conditions and scenarios

1.2.1. Global assessment of digital usages.

As such, a digital twin is not a new concept, because it has been de facto implemented since the very first deployment of digital systems in the electrical field.

Expected improvements linked to the deployment of digital twins have the ambition to address very diverse aspects such as ease of use, performance level, life span, cost of operation, cost of maintenance, as well as the improvement of the contribution of the given asset to the upper-level system in which this asset is used. Thus, many diverse stakeholders find interest in deploying those twins throughout the life cycle of these products/systems/assets such as system specifiers, system designer, purchasers, distributors, installers, operators, maintainers, asset managers, financial parties, service providers. Among these, one of the main interests for final users being to increase safety, assets lifespan (CAPEX – capital expenditure), as well as services availability (OPEX – operational expenditure), and thus on the global owner efficiency.

To get one step further, Table 2 lists the main usages which could be envisaged per types of digital twins, as broken down in the previous section.

Table 2 - Typical usages of digital twins per types

Type	Typical usages
Static twin	Procurement, asset management, static data
Functional twin	The above plus design, specification, condition monitoring and maintenance simulation to increase safety
Adaptive digital twin	The above plus predictions, advanced maintenance and simulations, synchronisation with real time data, possibly replacing part(s) of the physical asset if failing
Intelligent digital twin	The above plus a possible better selection and/or usage of the asset, autonomy, learning or replacing larger part(s) of the asset itself

2. Further characterization of digital twins usages applied to the electrical grid

2.1. The main dimensions of usage of digital twins

Considering a given asset (which could be a product, or a (sub-)system), digital twins of this asset may be considered in (at least) 3 different dimensions, as pictured in Figure 2, inspired by the SGAM approach [7] where the life cycle axe is replacing the interoperability axes.

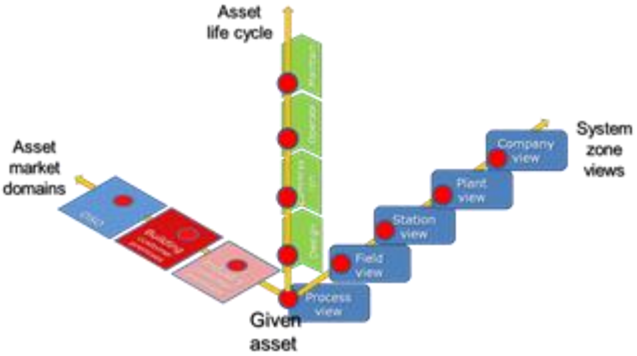

Figure 2 - Main dimensions of twin usages

2.2. The life cycle dimension

The same given asset is evolving during its life, and is crossing different steps, requiring the management of different aspects of the asset, with different levels of depth, but sharing many common data as exposed in Figure 2.

When considering the whole life cycle of assets, asset users already face many requirements related to asset-related data management, upon which many digital twins rely, and any work aiming at simplifying and optimizing such asset data management can only be beneficial.

The optimization of usage of a given asset all along the asset life cycle (including environmental performance) won't happen without handling a huge collection of data related to the asset itself, its operating environment and the system in which it is integrated.

Representing a conceptual life cycle of a given asset on a diagram (Figure 3), makes very clear that they are twins all along these steps, even before the physical asset exists (pre-digital twins), and possibly with very often two "variants": a "manufacturer's" view, or a "user's" view.

2.3. The system zones dimension

The same given asset is perceived differently depending the SGAM zone of the system the twin belongs to : at process level the twin is very close to the physical aspect of the asset, but at near-by level (field), some more real-time functional aspects of the asset may be considered by the twin, and at enterprise level, more financial aspects of the asset may be considered by the twin , such as its global life span, the cost of replacement, the supplying chain, etc. Finally, each zone will emphasis different aspects of the asset, with different level of depth, but sharing many common data.

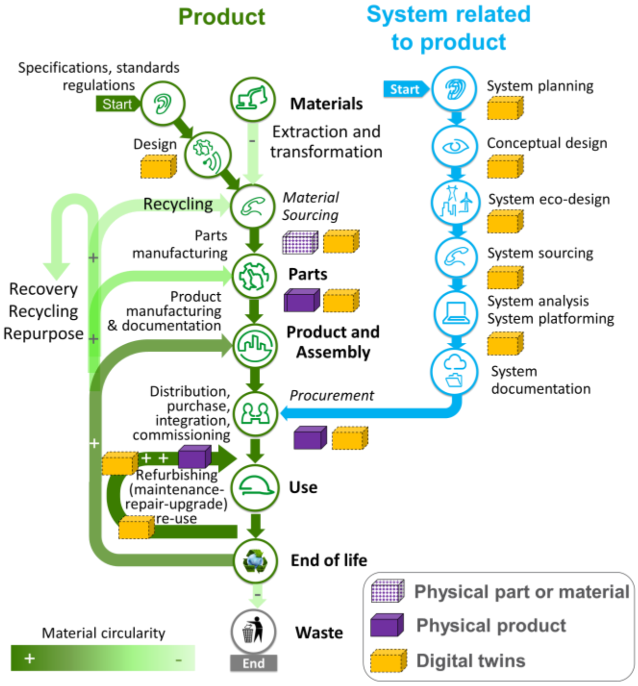

Figure 3 - Digital twins across the lifecycle of a given asset

For example, using the two first axes of Figure 2 (domains and system zones), Figure 4 shows the overlaps between the CIM (IEC 61970-61968) based twins and the IEC 61850 based twins (using respectively the CIM and IEC 61850 standard machine language to express assets properties), and conflicting potentially as well, with, as an example, the remaining links with the manufacturer side which may still host other twins of the same asset.

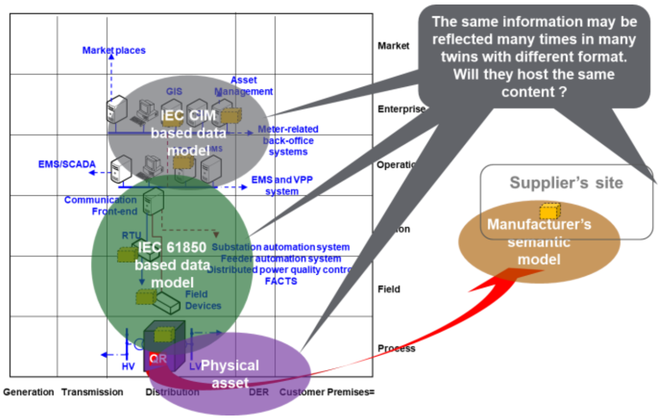

Figure 4 - example of twins data models heterogeneity in the context of the Smart Grid

To solve the interoperability issues between these twins based on semantic models (i.e., the seamless transition of product-related data from one namespace to another), some attempts for data model harmonization have led to the publication of IEC TS 62361-102 for CIM and IEC 61850 harmonization.

As detailed in Figure 2, each system zone is a potential host for digital twins of a given asset, here, as an example, a circuit-breaker (CB):

Table 3 - Twins across system zones applying to a circuit breaker

SGAM zone	**Typical twins**	**Type of twins**
process	Digital nameplate of the CB, possibly linked with a QR code to a set of data hosted by the CB manufacturer	Static twin
field	Twin to evaluate the normal response time of a CB and to react upstream in case of failure (breaker failure function)	Functional twin
station	Twin resulting from the collection of static and real-time data representing the CB,	Static or functional twin
operation	Twin reflecting the operation of the CB and the visualization of its state on the operator screen, with possible features to detect abnormal situations.	Functional or adaptive or even intelligent twin
enterprise	Twin hosted in the asset management system (based on data collected from various sources), with possible features helping to optimize its life span, and/or the maintenance cost.	Functional or adaptive or even intelligent twin

2.4. The market dimension

The same given asset may be used in different market SGAM domains such as distribution grid operator, industry, buildings customer premises. Each of these domains has its own ecosystem and will have different interests, and thus will request associated twins to focus on different aspects of the asset, with different levels of depth, but sharing many common data.

Such an approach could be of interest when considering the usage of twins in other reference models such as the smart manufacturing one (RAMI, NIST, …).

3. The reality of the digital twin deployment

Putting together all these different usages demonstrates the presence of many common properties as well as the presence of many common gaps. Common to all, the management of these twins suffers from important issues such as:

- the **cost & time of implementing** digital twins may be a stopper in many cases, compared to the expected benefits. It becomes of highest priority to reduce the cost and time of implementation, or to increase the value of the twin, to facilitate the integration of these twins within the targeted eco-system. Interoperable ontology would help to bridge domain-specific semantics (for distribution utilities versus private buildings) or to facilitate the integration of assets coming from different suppliers.
- **missing data**: The main reason for missing data, is the cost of supporting these, but not only. Anyone can understand that each additional data attached to a twin leads to an additional CAPEX cost and time (specification, commissioning, integration into the system and associated tests), and to an additional OPEX cost and time (cost of communication, hosting, archiving, and others). But it appears to be the consequence of lack of seamlessness between the different phases of the asset life cycle. For

example, a very common case is the one of data very important at the design phase, and at the maintenance phase, but not useful for operation. The lack of seamlessness between phase leads to data lost! Its re-creation for a given phase would lead to an additional process not reasonable in term of time & cost.

- **data quality management:** this important point is not very often considered while it is of key importance: the management of the quality of data (data in, own data, data out) affects the real value of a digital twin. It is also very often the consequence of data governance.
- **poor twins life cycle management** especially around their testing, their integration into layered systems and their update to follow the asset updates.
- **data consistency between the different twins of a given asset.** Effectively by essence, the different twins of a given asset are sharing the same set of data (especially all patrimonial data such as identification, type of asset …**).** The reality is that in most of the cases the content of these twins, following different build processes, are not coordinated, and are not sharing the same source of trust.

4. One path to overcome some main difficulties

4.1. Ontologies to facilitate semantic bridging

Ontologies promises is to provide a shared and common understanding of a domain that can be communicated between people and application systems. We can mention four main categories [8] of ontology application scenarios among which two [10] are of interest for the case of simplifying the deployment of digital twins:

4.2. Neutral Authoring

A given company or organization can benefit greatly by developing their own **"*Neutral Ontology*"** for authoring, and then developing translators from this ontology to the terminology required by the various target systems.

4.3. Common Access to Information

In any given area where legacy software systems are required to interoperate, it will always be necessary to translate between various formats and representations that evolved independently.

4.4. Digital twin and ontologies

Given the number of representation formats, the semantic interpretations of digital twin interfaces (and the digital thread) appear critical as these have to apply across different applications and/or different systems and/or different steps of the life cycle of the considered asset. Therefore ontology-based approaches could be of a great interest. Effectively, ontology could play a role in helping setting-up semantic bridges between interfaces of digital twins of the same asset (the same technical object, same technical properties).

This would make even more sense by **requesting standardisation to play a role in establishing and publishing this "*Neutral Ontology*"** as well as "standard" associations between information objects of this standard neutral ontology, and a given standard data model.

Such an approach could facilitate transferring semantic from one twin to another, even expressed through different data models. Although this may appear as a time-consuming effort, the benefits of this approach include knowledge reuse, improved maintainability, and long-term knowledge, while providing the ability to work with twins as they are. The very other important aspect is that any published ontology will have its own return on investment, no need for waiting for having a comprehensive approach to be usable. A similar case by case approach, depicted in the "*Common access to Information*" case, could apply in the situation of legacy twins, which would request a specific translator to the "neutral ontology" mentioned above.

5. The Grid digital twin (GDT)

5.1. Introduction

Electrical grids are complex systems that are continuing to increase in complexity. Observability and controllability of the real grid are being enhanced through the use of the GDT (i.e., the full model of the grid as it should be and behave) to better serve customers and predict failures with the deployment of smart meters, grid sensors, intelligent switches and data analytics. Conventional customers becoming active prosumers leads to an increasing complexity by the need of observing and possibly controlling these new active grid users.

This growth in complexity requires new decision support tools, for the design, simulation, optimization and maintenance of grid resources and associated assets, aka the lifecycle of the grid. This is about data management in a digital twin ecosystem. While simulating twins have been around for years, they were either embedded in proprietary software systems and poorly integrated environments, or in many other cases were suffering from the quality of data, and their lack of depth. These approaches are not sustainable in the new context and impede the ability to manage efficiently situational awareness with GTD.

The GDT is expected to expand in scope over time by addressing increasing utility needs, facilitating the coordination with external stakeholders and integrating all grid edge resources for localized and systemwide energy optimization with multiple objectives ranging from electro-technical to financial, and with granularity from individual assets. GDT will have to coordinate with the single source of truth. A prerequisite for such a future is to ease the flow of information between software systems and users along the lifecycle of the grid.

5.2. Digital twin within the utility

This GDT gradual expansion starts within the utility itself, here again with multiple threads.

The first example enables a coordination of the control and maintenance centres software, sharing the network model and its regular changes between GIS, ADMS, DERMS, etc. The model quality is permanently checked and updated if necessary, using the real-time data and electro-technical simulators. This is managing multiple versions of the model to cope with the different phases of the grid evolution: plan, design, model, simulate, operate, control, maintain, sunset.

A second application is a transparent integration between the control center and substations, with CIM/IEC 61850 data models being exchanged and replacing the traditional conversion often done with Excel and approximate semantic. This is first coping with the measurement data and is later expanded with protection and control setting, that might be adjusted dynamically at the central level.

Table 4 maps the different twin levels explained in section 1.2 with GDT examples. Real customer projects are using this today, often embedded into different software, but nested as well.

Table 4 - Grid Digital Twin Examples according to 1.2

Twin type	GDT examples
Static twin	Data model exchange between the control center and substation
Functional twin	Dynamic data model update and validation between ADMS and GIS Electro-technical and automation simulators, regarding the grid voltage and frequency control, network reconfiguration, etc. Protection selectivity simulators, recommending setting for different situations. Dependability simulators, aiming at optimizing the maintenance strategies and feeding the investment planning activities.
Adaptive	Grid edge simulators, forecasting power generation and demand on different time horizons, including DER and demand response impact. People simulator, aiming at optimizing the restoration capabilities especially when a storm is anticipated
Intelligent twins	Grid self-healing decision analytic Planning simulator, aiming at optimizing the investment scenario for grid and grid edge evolutions

5.3. Digital twin beyond the grid

As said in 5.1, there is an increased need for a coordination of systems beyond the grid, for making consumers, prosumers. This is about sharing model and real-time data to run simulators, a perfect fit for a twin but again with different flavors.

Integration between TSO is happening today leveraging CIM (IEC 61970/61968) models. Integration between TSO and DSO is yet limited but likely to expand in Europe, using again CIM as a common ontology to coordinate planning, operation and maintenance activities.

Integration with the grid edge, for instance integration of Distributed Energy Resources, requests as well shared ontology, and this is the purpose of IEC 61850 data model extensions to DER and microgrids. The benefits for the utility are a wider grid awareness or usage of distributed resources for grid automation (black start, volt-var, etc.). There are however several limiting factors:

- Lack of standardization at grid edge and/or absence of harmonization between the grid level (CIM) and some home standard (SAREF for instance). New work has started at IEC and CENELEC to “smoothen” this obstacle.
- Number of individual stakeholders involved, end users (residential, building, industrial) and technology providers. Each has in own agenda for standard adoption or participation to the smart grid for instance. This is today managed on a case-by-case basis but is hardly scalable, so a generic solution is still to be designed.

6. Conclusion

There are many dimensions for the digital twins, some being mature today but often embedded with the rest of the software, with many more being in development increasingly as a piece of software on its own that will have to be integrated with multiple database and software.

One dimension developed in this paper is about the data consistency all over the lifecycle of an asset or system of assets, reducing the twin build and maintenance costs to increase the business. Recommendation for a neutral ontology standard could facilitate interoperability in the future

Concerning the grid applications, concrete examples exist for the grid management software and the coordination of control centers and substations. This will be further developed in the future, for instance to integrate grid edge, improve the planning management or leverage the on-going substation virtualization for example

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