Digitalisation and Digital Twins in Photovoltaic Systems

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Executive Summary

The report "Digitalisation and Digital Twins in Photovoltaic Systems" provides a comprehensive overview of the transformative role of digitalisation within the photovoltaic (PV) sector, particularly through the integration of digital twins and advanced data models. We underscore the necessity of adopting digital technologies to enhance the operational efficiency, reliability, and overall performance of PV systems throughout their lifecycle.

Digitalisation is increasingly recognised as a crucial driver in the evolution of the PV industry, enabling stakeholders to improve decision-making processes, optimise system designs, and facilitate predictive maintenance. By integrating and leveraging vast amounts of data generated during the lifecycle of PV systems—from manufacturing through to operation and maintenance—digitalisation helps address critical challenges related to efficiency and sustainability in energy production.

Central to this transformation is the concept of the digital twin. We adopt the following definition:
"A digital twin is a virtual representation of a PV system or systems, at the appropriate level of detail, that can span its lifecycle, is updated from real data, and uses simulation, machine learning or reasoning to help decision making."

Digital twins enable stakeholders to simulate various operational scenarios, analyse performance under different conditions, and predict maintenance needs. This capability is particularly valuable in enhancing the reliability and performance of PV systems by allowing for proactive risk management and informed decision-making.

The report emphasises the importance of robust data models and structures, which are foundational to the successful implementation of digital twins. The establishment of standardised taxonomies and ontologies is essential for ensuring data interoperability and facilitating effective data sharing among various stakeholders in the PV industry. This is particularly relevant in the context of the Materials Data Science Ontology (MDS-Onto), which aims to unify terminologies and improve data integration across the sector. A critical aspect of interoperability is the so-called "FAIRification" of data (i.e., making data findable, accessible, interoperable, and re-usable).

Moreover, the report highlights the significant advancements in digitalisation along the entire PV value chain, from the manufacturing of components to the operational phase. Each stage benefits from digital tools that enhance automation, data analytics, and real-time monitoring, thereby reducing costs and improving performance outcomes. The integration of Internet of Things (IoT) technologies and artificial intelligence (AI) further enhances these capabilities, allowing for continuous improvement in PV system management.

We also highlight the challenges that remain, particularly in achieving full integration of digital processes across the PV value chain. Many current digitalisation efforts are still disconnected, and achieving a cohesive digital strategy requires collaborative efforts from all stakeholders involved. Additionally, the report stresses the critical need for effective cybersecurity measures as reliance on interconnected digital systems increases, emphasising that robust security protocols must be integrated into every phase of digital twin development and deployment.

In conclusion, the report outlines the potential for digitalisation, particularly using digital twins and robust data models, to support the photovoltaic sector. By optimising operational efficiency, enhancing predictive maintenance capabilities, and enabling better decision-making processes, digitalisation can not only improve the performance and reliability of PV systems but also contribute significantly to the broader goals of sustainability and energy transition. The continued advancement and adoption of innovative digital technologies will be crucial in shaping the future landscape of the PV industry.

Key Takeaways

- Digitalisation significantly contributes to risk analysis in PV projects, allowing stakeholders to quantify and mitigate risks associated with component failures, design flaws, and environmental factors.
- A digital twin is a virtual representation of a PV system that is continuously updated with real data and used for simulation and decision support throughout the system's lifecycle.
- The emphasis on the digital twin as a core concept signals its potential to revolutionise how PV systems are designed, operated, and maintained, ultimately contributing to the sector's growth and sustainability in the energy transition.
- Robust, standardised data models and ontologies—such as MDS-Onto—are essential for interoperable, FAIR data, enabling effective data sharing and forming the foundation for successful digital twin implementation in the PV industry.
- Two approaches to digital twinning are discussed: physics-based digital twins, which use physical models to simulate behaviour, and data-driven digital twins, which rely on real-world data to model system performance.
- By leveraging data from both the physical and virtual entities, digital twins enable detailed simulations of expected power outputs and help identify deviations from anticipated performance.
- The integration of artificial intelligence (AI) and the Internet of Things (IoT) are key components in optimising operations and maintenance (O&M) processes for PV systems.
- Cyber security is of utmost importance to be considered at all levels of digitalisation.