

Titre de la thèse/Thesis title :

Multimodal Data Integration and Adaptive Monitoring for Digital Twins in Renewable Energy Systems

Laboratoire d'accueil / Host Laboratory : FEMTO-ST, Energy department, SHARPAC Team

Spécialité du doctorat préparé/Speciality : Electrical Engineering (Section 63)

Mots-clefs / Keywords : Artificial Intelligence, diagnostics, digital twin, hybrid renewable energy sources, monitoring.

Descriptif détaillé de la thèse / Job description

Multimodal data integration has recently gained attention in energy and cyber-physical systems, as digital-twin accuracy depends on effective fusion of heterogeneous data sources [1]-[3]. Inconsistent or incomplete integration can reduce model reliability [1], while AI techniques manage variability, noise, and scalability in power-system datasets [2]. Unsupervised fusion improves over single-source monitoring [3], and distributed Bayesian methods handle uncertainty and network noise [4]. However, existing work rarely addresses continuous monitoring, forecasting, and scenario exploration simultaneously. Developing adaptive, uncertainty-aware frameworks remains a key research challenge.

Deep-learning adjustment models for evolving environmental conditions [5] and AI-powered digital twins for predictive maintenance [6] exist, but they often lack support for high-quality, well-integrated input data. Reliable digital-twin performance thus requires not only simulation fidelity but also robust data fusion and real-time adaptation. Current diagnostics and decision-making frameworks mainly use statistical tools for anomaly detection, yet choosing optimal maintenance actions remains challenging. IoT-based virtual replicas improve anomaly detection by filtering noise, extracting dependencies, and supporting real-time monitoring [7]. Inverse reinforcement learning (IRL) infers priorities from expert behavior under uncertainty [8], but its application to renewable-energy digital twins is limited. Therefore, a holistic digital framework integrating monitoring, diagnostics, and predictive maintenance tools is needed to enable reliable, uncertainty-aware operation of hybrid renewable-energy systems.

The aim of this PhD research is to develop an AI-driven framework for multimodal data integration, monitoring, and predictive maintenance in advanced digital twins for hybrid renewable energy systems (HRES) integrated with the power grid. The proposed framework will combine heterogeneous datasets, quantify uncertainty, enable adaptive anomaly detection, and integrate an inverse reinforcement learning (IRL) optimization layer for maintenance and operational decision support. The resulting uncertainty-aware digital twin aims to reduce downtime, improve system resilience, and support the reliable integration of renewable energy systems.

Références bibliographiques / Bibliography

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- [2] G. Rahmani-Sane, S. Azad, M. T. Ameli, and S. Haghani, "The Applications of Artificial Intelligence and Digital Twin in Power Systems: An In-Depth Review," *IEEE Access*, 2025.
- [3] M. McKinney et al., "Unsupervised multimodal fusion of in-process sensor data for advanced manufacturing process monitoring," *J. Manuf. Syst.*, vol. 78, pp. 271–282, 2025.
- [4] Y. Li, E. Zhou, and F. Zhang, "A Distributed Bayesian Data Fusion Algorithm with Uniform Consistency," *IEEE Trans. Autom. Control*, vol. 69, no. 9, pp. 6176–6182, 2024.
- [5] A. J. Hashim, M. A. Balafar, J. Tanha, and A. Baradarani, "Adaptive deep learning models for efficient multivariate anomaly detection in IoT infrastructures," *Appl. Soft Comput.*, vol. 167, Art. no. 112377, 2024.

[6] H. Shittu and M. Shittu, "AI Powered Digital Twins for Predictive Maintenance and Operational Optimization of Renewable Energy Systems," *Int. J. Sci., Archit., Technol. Environ.*, vol. 1, pp. 151–163, 2024.

[7] B. Bolat-Akça and E. Bozkaya-Aras, "Digital twin-assisted intelligent anomaly detection system for Internet of Things," *Ad Hoc Netw.*, vol. 158, Art. no. 103484, 2024.

[8] S. Arora and P. Doshi, "A Survey of Inverse Reinforcement Learning: Challenges, Methods, and Progress," *Artif. Intell.*, vol. 297, Art. no. 103500, 2021.

Profil demandé / Applicant profile

The candidate, holding (or currently enrolled in the final year of) a Master's degree or equivalent, must have strong skills in artificial intelligence, data analytics, optimization, and power/energy systems. A solid background in electrical engineering, machine learning and programming is essential. A good level of English is required.

Financement : MESRI Etablissement

Gross monthly salary: €2,300

Direction de la thèse / Thesis Supervisor : Issam SALHI / issam.salhi@utbm.fr

Encadrement de la thèse : co-encadrant / Co-supervisor Qian XUN / qian.xun@utbm.fr

Lieu / location : Belfort (90000), France

Application Guidelines

Applicants are invited to submit their applications directly to the PhD supervisors.

The application must include the following documents:

- **Cover Letter**
- **At least one reference letter** (from supervisors of previous internships or projects)
- **B.Sc. and M.Sc. Diplomas**
- **Academic Transcripts for both B.Sc. and M.Sc.**
- **Ranking Certificate for both B.Sc. and M.Sc.**
- **English Language Certificate (strongly recommended)**
- **Copy of Passport**
- **Detailed Curriculum Vitae (CV)**

The CV must include the following information: personal address, employer's address (or university address for students), date of birth, personal and professional email addresses, gender (Mr. or Ms.), and nationality.

All addresses must specify street number, street name, city, and country. A phone number with international dialing code must also be provided.

Important dates:

Application deadline: May 11, 2026

Preliminary selection notification: May 18, 2026

Interviews: May 25, 2026

Contract start date: October 1, 2026