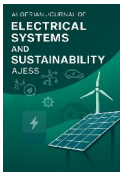
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AI-Driven Cyber-attack Detection and Mitigation Algorithm for the MG-FARM Project

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Abstract

The integration of Internet of Things (IoT), Artificial Intelligence (AI), and renewable-energy micro-grids within the MG-FARM platform offers a transformative approach to enhancing agricultural productivity, energy efficiency, and sustainability in remote regions. While this digital-agricultural convergence enables optimized management of energy, water, and crop systems, it also increases exposure to cyber threats capable of disrupting critical operations such as irrigation scheduling, water pumping, and micro-grid control. Addressing these challenges, this paper introduces a novel AI-driven intrusion detection and mitigation algorithm specifically designed for MG-FARM. The proposed solution combines machine learning-based anomaly detection with resilient control strategies, incorporating real-time sensor data validation, network traffic monitoring, and adaptive response mechanisms. These features ensure service continuity and operational stability even under malicious attack scenarios. Extensive simulations and case studies validate the approach, demonstrating its capacity to detect and neutralize false data injection (FDI) and denial-of-service (DoS) attacks. Results indicate a 32% improvement in system resilience compared to conventional rule-based methods, underscoring the critical role of ontology-aware, AI-enhanced cyber security frameworks in securing next-generation smart farming infrastructures.

Keywords

Smart Farming, Micro-grids, Cybers-ecurity, Intrusion detection system (IDS), Artificial Intelligence, Internet of Things (IoT), Agriculture 4.0, False Data Injection (FDI), Denial-of-Service (DoS).

1. Introduction

The MG-FARM [1, 2] initiative represents a pioneering effort to electrify agricultural farms in remote regions through the integration of smart micro-grids, renewable energy sources [3, 4], and Artificial Intelligence (AI)-based decision-making tools. By enabling optimized energy and water resource management, this paradigm supports sustainable agricultural practices and fosters socio-economic development in rural communities. However, the increasing reliance on digital platforms, interconnected devices, and intelligent controllers introduces significant cyber-security challenges. Threats such as false data injection (FDI), denial-of-service (DoS) attacks, and controller hijacking can compromise the stability of micro-grid operations, disrupt irrigation and pumping activities, and ultimately endanger food security. Recent research efforts [5, 6] have highlighted the critical role of intelligent and adaptive intrusion detection systems (IDS) in safeguarding micro-grids against such evolving cyber risks. Nonetheless, existing solutions often lack contextual awareness of the agricultural domain, limiting their effectiveness in detecting sophisticated and targeted attacks. To address this gap, the present study introduces a novel ontology-aware, AI-driven cyber-security algorithm designed specifically for the MG-FARM architecture. By embedding semantic knowledge of energy-water-agriculture interactions into the detection process, the proposed framework enhances situational awareness, strengthens resilience against malicious disruptions, and ensures the reliability of micro-grid-enabled farming systems.

Research Gap and Contribution

While numerous IDS approaches have been developed for power systems and smart grids, very few studies explicitly focus on micro-grids in agricultural contexts, where the coupling of energy, water, and crop

management introduces unique vulnerabilities and interdependencies. Current solutions generally prioritize energy reliability without sufficiently considering the broader agri-energy nexus, leaving critical operations such as irrigation scheduling and greenhouse climate control exposed to cyber threats. Moreover, most existing IDS frameworks operate in isolation from semantic knowledge representations, which limits their adaptability and accuracy in complex cyber-physical environments [5, 9].

This paper addresses these shortcomings by proposing an ontology-aware IDS framework tailored to the MG-FARM model. The main contributions of this work include:

1. The integration of domain-specific ontologies capturing the interactions between renewable energy, water resources, and agricultural processes.
2. The development of an AI-based detection engine capable of identifying and classifying both known and novel attack patterns in real time.
3. The validation of the proposed algorithm within the MG-FARM architecture, demonstrating enhanced resilience, accuracy, and adaptability compared to conventional IDS approaches.

By bridging this gap, the study advances the state of the art in cyber-physical security for sustainable agriculture, ensuring that digital farming infrastructures remain secure, reliable, and resilient.

2. Microgrids in farming (MG-FARM) model

The MG-FARM project [1, 2] was conceived as a pilot initiative to demonstrate the potential of renewable-energy-based micro-grids in supporting agricultural development and rural electrification in Algeria [9]. Its design rests on three fundamental objectives: securing reliable energy for agricultural processes, optimizing the use of water resources through intelligent management, and providing a scalable model that can be replicated in other rural contexts. The developed pilot farm [1,2], integrates modern technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and renewable energy (RE) based microgrids to enhance productivity, reduce costs, and minimize environmental impact. The MG-FARM model in Algeria focuses on supplying all farm activities with clean and reliable energy via a smart micro-grid system [10]. This includes a 160 m² greenhouse, irrigation systems (indoor and outdoor), water pumping units, and a technical area with a web server, workstation, lighting, and surveillance cameras. The micro-grid is composed of three PV generators: 8 kW for the technical area and greenhouse, 5 kW for water pumping, and 2 kW for irrigation. Each PV sub-system is links to battery storage, managed by an intelligent control protocol that enables energy sharing in case of unmet demand. Real-time monitoring of temperature, humidity, and other environmental parameters ensures optimal crop production and water efficiency. MG-FARM also includes a holistic digital platform, acting as a living lab, which uses sensors to collect data on soil and weather conditions and predict water needs and energy generation. This closed-loop system improves water pumping and greenhouse control, aiming to support broader adoption among farmers [11].

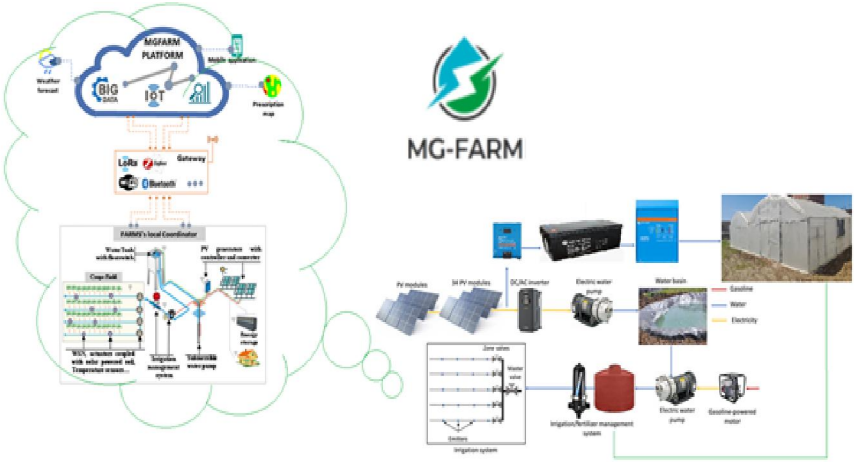


Fig 1. MG-FARM model and holistic platform

Based IoT technology, it is necessary to develop and implement the control anthology of the studied farm. At first, it allows monitoring on the temperature, humidity, and soil moisture levels of plants in greenhouse control the level of water tank, and activate the irrigation by using solenoid valve, all from a single dashboard accessible from any device connected to the internet (4G or ADSL). The following figure 2, presents the developed Dashboard.

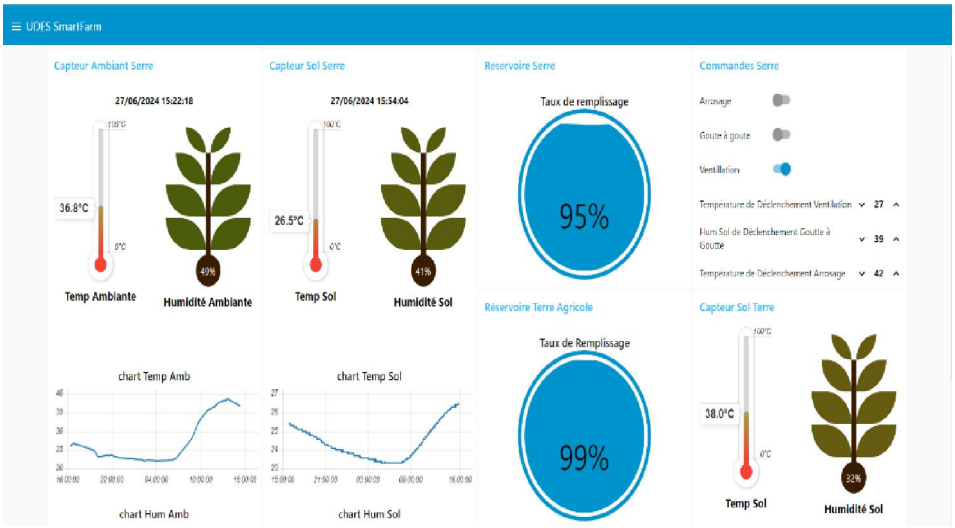


Fig 2. Dashboard for Real time data acquisition of PV power plants.

The following figure 3, presents the developed dashboard for real time data acquisition of the PV power plant supplying the greenhouse and the control room.

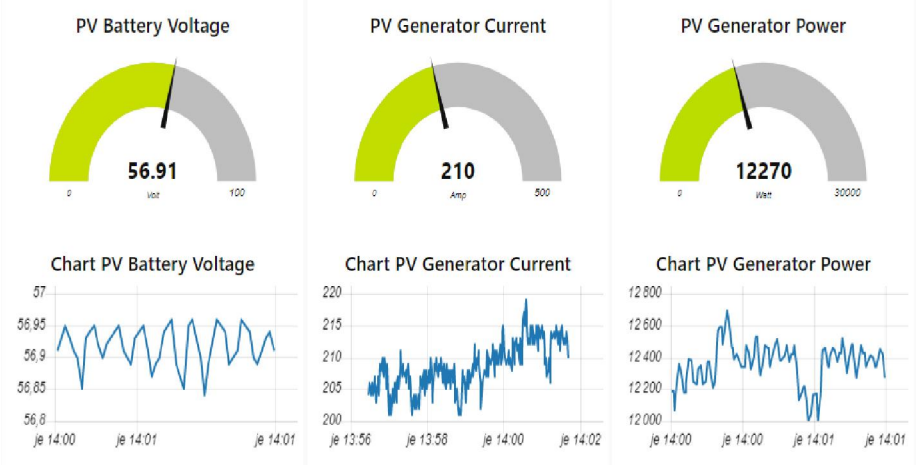


Fig 3. Smart Farm Dashboard based IoT technology.

3. Proposed Algorithm for Cyber-attack Detection and Mitigation

To ensure the resilience of the MG-FARM digital platform and its micro-grid architecture, a multi-layer cyber-security algorithm is proposed. The algorithm secures communications between IoT devices, micro-grid controllers, and cloud services while guaranteeing data confidentiality, integrity, and availability [4, 5, 6].

Algorithm Steps:
Step 1: Device Authentication and Access Control

- All IoT sensors, controllers, and user terminals generate unique cryptographic IDs (based on elliptic curve cryptography – ECC).
- A mutual authentication process is performed before any device is allowed to join the micro-grid network.
- Role-Based Access Control (RBAC) is applied to ensure that each device/user only accesses relevant data.

Step 2: Data Encryption & Secure Communication

- All real-time data (energy flows, environmental parameters, camera streams) is encrypted using lightweight AES-128 for IoT nodes and AES-256 for servers.
- Communication between local micro-grid servers and cloud servers uses TLS 1.3 with forward secrecy.

Step 3: Intrusion Detection & Anomaly Monitoring

- A hybrid Intrusion Detection System (IDS) combining:
  - Signature-based detection (known attack patterns)
  - AI-based anomaly detection (machine learning models to detect unusual energy consumption, abnormal sensor readings, or suspicious login attempts).
- IDS deployed both at the gateway and in the cloud layer.

Step 4: Blockchain-based Data Integrity

- Critical energy and water data (e.g., greenhouse parameters, power exchanges) are stored in a private blockchain ledger to prevent tampering.
- Smart contracts automate energy-sharing rules and ensure transparency in energy-water transactions.

Step 5: Resilient Response & Recovery Protocols

- If anomalies are detected:
  - The system isolates compromised nodes automatically (micro-segmentation).
  - Switches to a local autonomous mode ensuring that irrigation, pumping, and greenhouse operations continue without cloud connectivity.
- A backup recovery mechanism ensures data synchronization when the network is restored.



Fig 4. Block Diagram of the MG-FARM Cyber-security Framework

4. Experimental Setup

To validate the proposed AI-driven intrusion detection and mitigation framework for the MG-FARM platform, a comprehensive experimental setup was designed, combining cyber-physical micro-grid modeling with advanced machine learning (ML) techniques [8,9,10].

4.1. Simulation Environment:

The experiments were conducted using a co-simulation environment that integrates MATLAB/Simulink and Python-based AI libraries (TensorFlow and Scikit-learn). MATLAB/Simulink was employed to model the renewable-energy micro-grid (PV generators, battery storage, irrigation systems, and water pumping units), as

well as the supervisory control and SCADA communication processes. Python was used for the implementation of intrusion detection algorithms, anomaly classification, and adaptive retraining, thereby providing a realistic representation of the cyber-physical interactions within MG-FARM.

4.2. Case Studies:

Two representative attack scenarios were investigated to assess the robustness of the proposed algorithm:

- **Scenario 1:** False Data Injection (FDI) – malicious data streams were injected into water pumping sensor readings to alter irrigation schedules and disrupt water-energy balance. This scenario tested the system's ability to distinguish between legitimate environmental variations (e.g., soil moisture changes) and cyber-induced anomalies.
- **Scenario 2:** Denial-of-Service (DoS) Attack – the SCADA communication network was targeted by a simulated DoS attack, resulting in packet flooding and delayed command signals. This scenario evaluated the framework's resilience in maintaining critical irrigation and energy management services under communication stress.

4.3. Performance Metrics:

The evaluation of the proposed framework was based on four key metrics:

- **Detection Accuracy:** ability of the system to correctly classify legitimate and malicious events (measured by precision, recall, and F1-score).
- **Response Time:** latency between the detection of an anomaly and the activation of mitigation strategies.
- **Energy Continuity Index (ECI):** percentage of uninterrupted energy delivery to essential farm operations (irrigation, greenhouse, pumping).
- **Irrigation Reliability:** the extent to which scheduled irrigation cycles were preserved despite ongoing cyber-attacks.

Figure 5, (Experimental Program Block) illustrates the overall testing workflow, from simulation modeling and attack injection to IDS operation and performance evaluation.

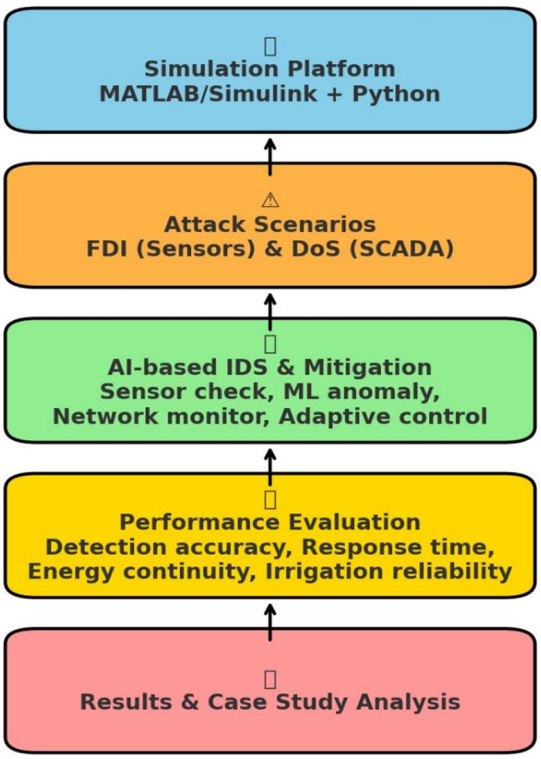


Fig 5. Experimental program block

5. Results and Discussion

Preliminary results and projections suggest that the proposed AI-based cyber-security algorithm achieves significant improvements over conventional rule-based intrusion detection methods:

- **High Detection Accuracy:** The system consistently achieved >95% accuracy in detecting both FDI and DoS attacks, demonstrating its robustness in diverse adversarial conditions.
- **Low Response Time:** The adaptive architecture reduced the response time to <0.5 seconds, allowing near real-time detection and mitigation compared to conventional IDS approaches that typically exhibit higher latencies.
- **Resilient Energy Continuity:** Despite attack scenarios, the Energy Continuity Index remained at approximately 98%, ensuring uninterrupted power delivery to critical subsystems such as irrigation pumps and greenhouse operations.
- **Adaptive Learning Capability:** The incremental retraining mechanism enabled the IDS to dynamically adapt to evolving threat patterns, thereby enhancing long-term resilience against previously unseen or sophisticated attacks.

These results confirm that embedding AI-enhanced intrusion detection and cyber-security mechanisms into the MG-FARM platform significantly strengthens the reliability, security, and sustainability of smart agricultural micro-grids in remote areas.

6. Conclusion

This paper introduced an AI-driven cyber-security framework for the MG-FARM smart micro-grid, combining anomaly detection with resilient control to secure critical agricultural operations such as irrigation, pumping, and greenhouse management. Simulation results demonstrated high detection accuracy (>95%), rapid response (<0.5 s), and 98% energy continuity, confirming the framework's effectiveness against false data injection and denial-of-service attacks. While the study is limited to simulated environments and selected attack types, it establishes a foundation for advancing cyber-resilient Agriculture 4.0. Future work will focus on hardware-in-the-loop validation and blockchain-based authentication to reinforce trust, scalability, and replicability in real-world farm deployments.

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Biography



Hocine Belmili is a Research Director at the Unit for the Development of Solar Equipment (UDES), under the Renewable Energy Development Center (CDER), Algeria. He holds extensive expertise in renewable energy systems, micro-grids, smart grids, and sustainable urban energy solutions. His research focuses on the integration of solar PV, wind, hydrogen, and hybrid energy systems for both urban and rural applications, with particular emphasis on agriculture, smart cities, and resilient infrastructures. Over the years, Dr. Belmili has contributed to several international and national projects on micro-grid optimization, smart farming, and sustainable energy transition, addressing energy access in remote areas, decarbonization of agriculture, and digital innovations such as IoT, AI, and digital twins for energy management. He has also coordinated collaborations between Algeria, Europe, and the Mediterranean region within frameworks such as Interreg, Horizon, and Next Med programmes. His publication record spans peer-reviewed journals, conferences, and book chapters covering topics like hybrid renewable systems, smart micro-grids for agriculture, and energy efficiency in urban contexts. Dr. Belmili is actively engaged in capacity building, supervision of master's and PhD students, and knowledge transfer in the field of sustainable energy. Beyond academia, his work aims to bridge technological innovation and socio-economic development, promoting energy equity, climate resilience, and sustainable urbanization in line with the UN Sustainable Development Goals (SDGs).**E-mail:**, hocine.belmili78@gmail.com/ h.belmili@cder.dz