Cyber-Resilient Digital Twin of a Bidirectional EV Ultra-Fast Charger for Secure and Sustainable Transportation

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RESEARCH MOTIVATION

Problem Statement

- The growing deployment of bidirectional EV charging infrastructure introduces cyber-physical vulnerabilities that can compromise power conversion, DC-link stability, and grid-interactive operation.
- Conventional chargers lack intelligent mechanisms to distinguish cyberattacks from normal operating disturbances, creating a need for real-time monitoring and resilient control.

Research Goal

- Develop an AI-enabled, cyber-resilient digital twin of a bidirectional DC fast charger for intelligent anomaly detection, cybersecurity assessment, and reliable Vehicle-to-Everything (V2X) operation.

Proposed Solution

- **Advanced Power Conversion:** Wide-bandgap (WBG) devices and a Dual-Active-Bridge (DAB) converter.
- **Digital Twin:** Real-time virtual representation using an OPAL-RT-based real-time simulator.
- **AI-Enabled Cybersecurity:** Intelligent anomaly detection and cybersecurity-aware resilient control.

RESEARCH QUESTIONS

1. How can a high-fidelity digital twin accurately represent bidirectional charger dynamics and operating conditions in real time?
2. How effectively can AI identify cyberattacks and distinguish malicious signal manipulation from physical disturbances?
3. How can digital twin-assisted resilient control maintain stable power conversion and bidirectional energy transfer under cyber-compromised conditions?

RESEARCH METHODOLOGY

Bi-directional Electric Vehicle Charger Modelling
Wide-band gap devices · Dual active bridge topology · High-frequency transformer · V2X control

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Digital Twin Development
Virtual converter model · Model synchronization · State monitoring

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AI-Based Anomaly Detection
Data acquisition · Feature extraction · AI training · Anomaly classification

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Cyberattack Assessment
False-data injection · Signal manipulation · Communication delays · Unauthorized commands

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Resilient Control and OPAL-RT Validation
Threat detection · Control response · Real-time simulation · Hardware-in-the-loop assessment

Fig. 1 Cyber-Resilient Digital Twin methodology

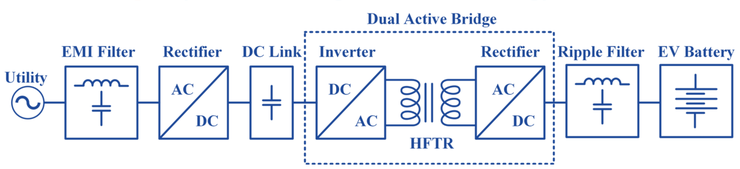


Fig.2 DAB-based EV Ultra-fast charger block diagram

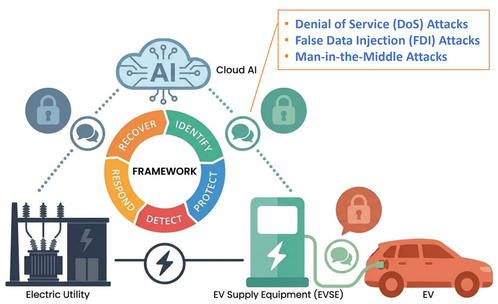


Fig.3 Cyber-physical structure and framework of EV charging infrastructure [1]

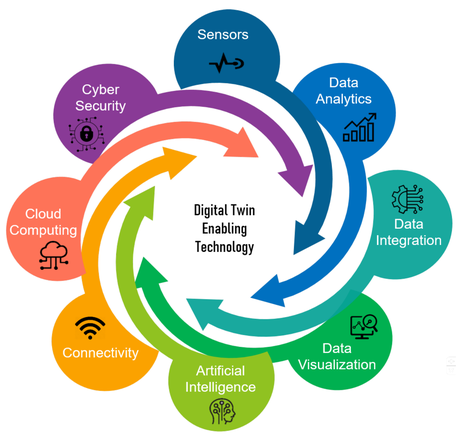


Fig.4 Digital twin enabling technology [2]

RESULTS AND VALIDATION

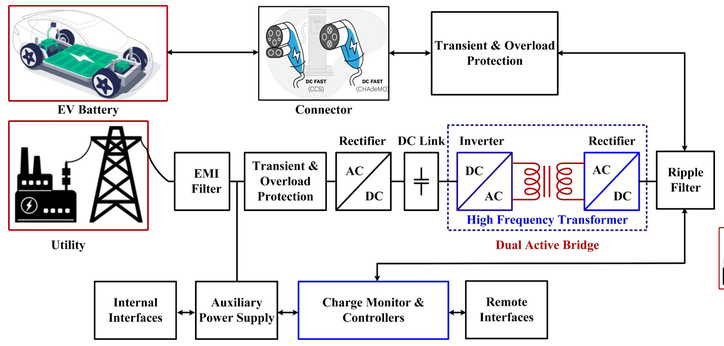


Fig.5 Grid-connected DC fast charging system configuration [3]

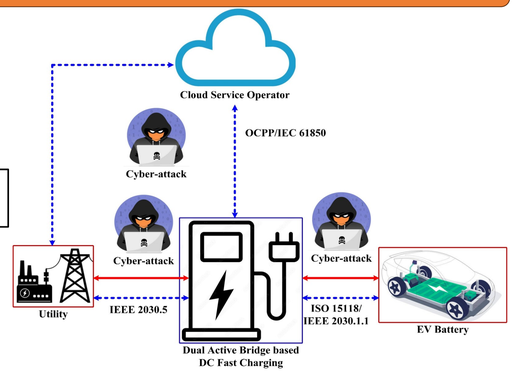


Fig.6 Cyber-physical nexus of the DC fast charging system

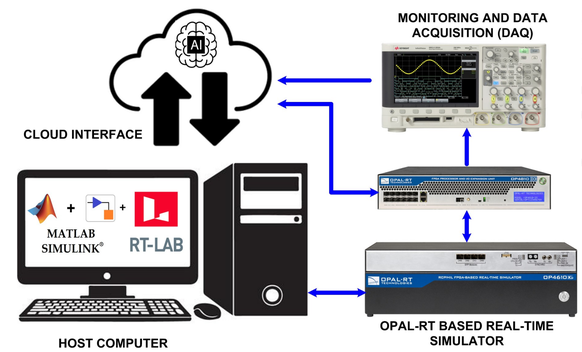


Fig.7 OPAL-RT based Digital Twin of an EV Ultra-fast charger

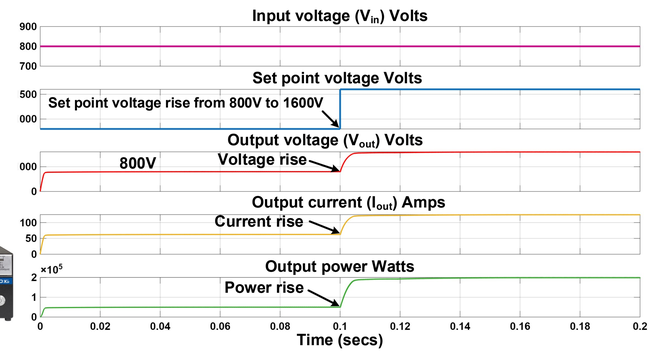


Fig.8 Set Point Injection Attack on DAB Converter Controller

DISCUSSION AND IMPACT

Sustainable Development Goal (SDG) 7: Supports efficient bidirectional EV charging and intelligent energy management to promote reliable and cleaner electricity utilization.

SDG 9: Advances innovative power electronics, AI-enabled digital twin technology, and cyber-resilient charging infrastructure through real-time simulation and validation.

SDG 11: Promotes secure and reliable EV charging networks, supporting transportation electrification, cleaner urban mobility, and grid-interactive energy infrastructure.

SDG 12: Encourages efficient energy utilization, optimized charging and discharging, and improved use of existing energy infrastructure through intelligent monitoring and predictive assessment.

SDG 13: Supports transportation decarbonization through bidirectional EV charging, improved grid flexibility, and sustainable energy management.

CONCLUSIONS

- ✓ The proposed digital twin integrates advanced power electronics, intelligent anomaly detection, and cybersecurity-aware control to advance resilient bidirectional EV charging infrastructure.
- ✓ Through OPAL-RT-based real-time validation, the framework aims to identify cyber threats, assess abnormal operating conditions, and maintain stable energy exchange in V2X applications.
- ✓ This research provides a foundation for secure, intelligent, and sustainable electric mobility.

SECURE • INTELLIGENT • ADAPTIVE • SUSTAINABLE

REFERENCES

[1] J. Shaw, "***Fast charging's rapid rise raises EV security risks***," EEPower, Oct. 1, 2024. [Online:https://eepower.com/tech-insights/fast-chargings-rapid-rise-raises-ev-security-risks/]

[2] N. Kumari, A. Sharma, B. Tran, N. Chilamkurti, and D. Alahakoon, "***A comprehensive review of digital twin technology for grid-connected microgrid systems: State of the art, potential and challenges faced***," Energies, vol. 16, no. 14, Jul. 2023, Art. no. 5525.

[3] **V.S.R.Varaprasad Oruganti**, K. T. Lulbadda, T. Sidhu, and S. Williamson, "***A study of cybersecurity and resilience of dual active bridge converters in electric vehicle fast charging systems***," in Proc. IEEE Int. Conf. Power Electron., Smart Grid, Renew. Energy (PESGRE), Dec. 2025, pp. 1–6.

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