ICT1099AI04 - AI-Driven Digital Twin and Multi-Agent Reinforcement Learning for Vehicle-to-Grid Smart Parking in Bahrain

Principal Investigator

Dr. Shahnawaz Khan	
Polytechnic ID: 12010895	**Department/School**: ICT

Programme	ICT1099 PhD in Computer Science
Research Area and Specialization:	AI-Driven Energy Management, Smart Grid Technologies, Vehicle-to-Grid (V2G) Integration and Control, Power System Modeling & Digital Twins Simulation
Company Endorsement	DERASAT
Industry mentor	Dr. Abdulla Isa Al Abbasi

Background of the problem

Bahrain's electricity demand is driven by summer cooling. The Authority recorded an all-time peak of 3,798 megawatts in August 2023, and demand is expected to reach about 6.5 gigawatts by 2030. Across the region, cooling causes close to half of the peak. At the same time Bahrain is adding solar power and aims for 20 percent renewables by 2035 and over 45 percent clean supply by 2040. Solar fades in the early evening, just as cooling demand stays high, so the grid needs flexible storage to fill that gap. A growing electric vehicle fleet is a large pool of idle batteries that could provide exactly this. Bahrain's new 2025 charging rules now allow vehicle-to-grid export under utility approval and metering, which creates a clear opening for this research to guide policy.

This project studies how electric vehicles parked at workplaces, malls, and public sites in Bahrain can support the power grid while still charging for their drivers. The idea is to build a digital twin, a real-time computer model of the grid, the parking facilities, the chargers, and the solar supply, and to test smart control strategies on it. A machine learning controller will decide when each group of vehicles should charge, hold, or send power back to the grid. Many parking sites are then combined into a single resource, a virtual power plant, that the utility can call on at peak times. The whole framework is tested fully in simulation, so no physical hardware is needed.

List of publications related to the field

- Siddiqui, S., Ayub, A., Ahmed, G., Aziz, A., & Al-Abdullah, M. (2026). Autonomous smart contract deployment through generative AI and Blockchain in smart urban mobility. Cluster Computing, 29(4), 215.
- Rizvi, S. R., Zehra, S., & Olariu, S. (2026). From smart cities to smart homes: the role of vehicular networks in digital twin ecosystems. In Home Digital Twins (pp. 361-377). Elsevier.
- Pandey, A. K., B, A., & Krishnamurthy, N. K. (2026). Optimizing electric vehicle fleets to develop smart charging infrastructure: a digital twin approach. Sustainable Energy Research, 13(1), 8.
- Saba, I., Alobaidi, A. H., Alghamdi, S., & Tariq, M. (2025). Digital twin and TD3-Enabled optimization of xEV energy management in Vehicle-to-Grid Networks. IEEE access.
- Costa, M., & Del Papa, G. (2025). Digital twins for intelligent vehicle-to-grid systems: A multi-physics EV model for AI-based energy management. Applied Sciences, 15(15), 8214.
- Shaker, H., Sharef, Z. T., Abbas, S., & Khan, S. (2025). Vehicle to infrastructure routing protocols: AI and finance perspectives. In Innovations in Blockchain-Powered Intelligence and Cognitive Internet of Things (CIoT) (pp. 341-388). IGI Global Scientific Publishing.
- Imam Rahmani, M. K., Khan, S., Ahmed, M. E., & Jawad, K. (2024). An Intelligent Transport System for Prediction of Urban Traffic Congestion Level. International Journal of Advanced Computer Science & Applications, 15(11).
- Nadeem, Z., Khan, Z., Mir, U., Mir, U. I., Khan, S., Nadeem, H., & Sultan, J. (2022). Pakistani traffic-sign recognition using transfer learning. Multimedia Tools and Applications, 81(6), 8429-8449.

Research Objectives and Expected Outcomes:

Aim

The aim is to design and test, using a real-time digital twin, a smart control framework that lets parked electric vehicles support the Bahrain grid.

Objectives:

The objectives are to build the digital twin of a Bahrain feeder with parking, chargers, and solar; to develop machine learning controllers that coordinate many vehicles at once; to measure the grid services they can provide, such as peak reduction, frequency support, and voltage support; to model how Bahrain's extreme heat affects battery performance and aging; and to turn the results into tariff and connection guidance for the utility.

Expected Outcomes

- A fully operational and validated digital twin model of a Bahrain distribution feeder, successfully integrating solar PV generation, EV charging infrastructure, and parking facilities.
- A robust, ML-based smart control system capable of aggregating, coordinating, and optimizing the charging and discharging cycles of multiple parked electric vehicles simultaneously.
- Quantified grid service metrics specifically measuring peak load reduction, frequency regulation, and voltage stabilization.
- A detailed assessment and predictive model characterizing how Bahrain's extreme ambient heat impacts EV battery performance.
- Evidence-based policy recommendations for Bahrain's utility providers.

Research Design/Methodology

The core method is real-time simulation, which runs the model in step with real clock time and lets the controller be tested in a realistic closed loop. Everything is done in simulation, so no physical equipment is required.

The proposed work moves in four steps.

- First, build the digital twin of a representative Bahrain feeder with parking facilities, chargers, solar, and a demand profile calibrated to the summer cooling peak, with vehicle arrivals and departures modeled from real parking patterns.
- Second, prepare the data and forecasting, generating mobility, charging, weather, and load data, and training models that predict occupancy, energy needs, solar output, and demand.
- Third, develop and compare controllers, testing simple rule-based and model predictive methods against single-agent and multi-agent reinforcement learning, with safety checks that protect voltage, current, and each driver's required charge.
- Fourth, validate and stress-test on the twin under high vehicle adoption, high solar, extreme heat, and dynamic pricing, measuring peak relief, grid stability, battery wear, and driver satisfaction.

A final step converts the findings into economic and policy guidance on tariffs, connection limits, and market participation, in line with the utility's framework.

Significance and potential impact of research in Bahrain

Significance

The project brings together four new ideas. It builds one of the first real-time digital twins made for a hot, cooling-driven Gulf grid rather than a temperate one. It uses multi-agent learning, where each parking site acts as its own decision-maker, which scales better than controlling every vehicle from one center. It treats the combined sites as a virtual power plant that can offer several services at once. And it is climate-aware, modeling directly how Bahrain's heat affects battery aging, an effect that studies from cooler climates usually ignore.

Potential Impact

The project delivers a Bahrain-specific digital twin for vehicle-to-grid study, a scalable multi-agent control method, new evidence on how Gulf heat shapes vehicle-to-grid performance, and a decision-support tool and policy guidance that support Bahrain's energy transition and net-zero goals.

Alignment with Bahrain’s national research strategy

Contribution to Bahrain Society: The project directly improves the daily life of Bahraini citizens by mitigating the risk of power outages during extreme summer cooling peaks and introducing smart V2G tariff structures that financially reward EV drivers without disrupting their mobility needs.

Alignment with Industry: This research is directly synchronized with the Kingdom's energy infrastructure by utilizing Bahrain’s landmark 2025 charging regulations to develop operational vehicle-to-grid (V2G) frameworks that align with utility metering and approval standards.

National Priorities: The study directly advances Bahrain's national strategic priorities and Economic Vision 2030 by offering climate-aware engineering models that help transition the grid toward the national target of 20 percent renewable energy integration by 2035.

Benefits for Industry: Bahraini electricity utilities and commercial infrastructure operators benefit from a scalable, simulated virtual power plant model that actively shaves severe peak cooling demands, thereby deferring highly expensive physical network upgrades.