MarSum Solutions: AI and Digital Twin Applications in Power Electronics

Artificial intelligence (AI) and digital twin technologies are beginning to change how power electronics are designed, controlled, validated, and maintained. Modern converters, inverters, motor drives, chargers, and grid interfaces already generate large amounts of electrical, thermal, and diagnostic data. The next step is to use that data, together with physics-based models and engineering judgment, to improve performance and reduce risk across the full product lifecycle.

The opportunity is not simply to add an AI feature to a converter. The value comes from connecting design tools, simulation models, embedded controls, sensor data, test results, and field operation into a disciplined engineering workflow. Used well, AI and digital twins can accelerate design exploration, improve control behavior, detect developing faults earlier, and support more reliable maintenance decisions. Used poorly, they can create opaque models, nuisance alarms, unvalidated control behavior, and false confidence.

This paper explains how AI and digital twins apply to power electronics, where they are most useful today, and what integration challenges must be solved before they become trusted engineering tools in production systems.

Why AI matters in power electronics

Power electronics design is increasingly multi-variable. Engineers must balance efficiency, switching frequency, electromagnetic interference (EMI), thermal behavior, power density, device stress, control bandwidth, reliability, manufacturability, and cost. As converters become faster, denser, and more software-defined, the number of design tradeoffs grows faster than traditional hand-tuning methods can comfortably manage.

AI methods can help by finding patterns in simulation results, test data, and operating histories. Machine-learning models can act as fast surrogate models for loss, temperature, electromagnetic compatibility risk, or lifetime estimates. Optimization algorithms can search large design spaces more quickly than manual iteration. Predictive models can identify abnormal behavior before a converter trips or fails. The most useful systems combine data-driven models with physics-based constraints so the result remains explainable and testable.

What is inside an AI-enabled power electronics workflow

AI-enabled power electronics is best understood as a workflow, not a single tool. The engineering blocks below need to be connected carefully so the result supports real design, validation, and operation decisions.

Data sources and instrumentation

Useful AI starts with reliable data. Converter voltage, current, temperature, switching state, fault history, vibration, environmental conditions, and operating mode must be measured consistently and tied to the real hardware configuration.

Machine-learning and optimization layer

Regression models, classifiers, anomaly detection, Bayesian optimization, and physics-informed learning can be used to predict performance, search design spaces, tune controls, or flag abnormal operation.

Embedded and edge deployment

Some functions run in design tools or cloud workflows. Others must run on embedded controllers, edge gateways, or test stands with real-time limits, cybersecurity requirements, and deterministic failure behavior.

Physics-based models

Circuit simulation, thermal models, electromagnetic models, control models, and reliability models provide engineering structure. They prevent AI tools from treating the converter as an abstract data problem disconnected from device physics.

Digital twin representation

A digital twin connects a model of the converter, motor drive, or power system to measured data. It can simulate expected behavior, compare it to actual operation, and update health or performance estimates over time.

Validation and governance

AI outputs must be traceable, version-controlled, and validated. Requirements, data quality, model limits, acceptance criteria, and fallback behavior should be defined before results are used for control or maintenance decisions.

AI applications across design, control, and maintenance

The strongest AI use cases are specific. They improve an existing engineering decision rather than replacing the engineer. In power electronics, those decisions commonly appear during design optimization, controller development, fault detection, and field maintenance.

Automated design space exploration: AI-assisted optimization can evaluate candidate combinations of semiconductor devices, switching frequency, magnetics, filters, thermal paths, and control settings. Surrogate models can reduce the number of full simulations needed while still guiding engineers toward practical tradeoffs.

Converter control optimization: Machine-learning-assisted control can support tuning, adaptive compensation, model predictive control, and operating-point optimization. The goal is usually better transient response, lower loss, reduced ripple, or improved robustness under changing loads and input conditions.

Predictive fault detection: Converters often show early warning signs before failure: temperature drift, abnormal ripple, increased switching stress, changing fan or pump behavior, intermittent trips, or sensor disagreement. AI can help detect patterns that fixed thresholds may miss.

Manufacturing and test analytics: Production test data, end-of-line measurements, burn-in results, and warranty returns can be used to identify weak process steps, component variation, calibration drift, and failure modes that do not appear clearly in a single prototype test.

Digital twins for converters, drives, and power systems

A digital twin is more than a simulation file. For power electronics, a useful digital twin combines a model of the physical system with operating data from the actual converter, drive, or plant. The twin can estimate internal states that are difficult to measure directly, compare expected behavior against real behavior, and support decisions about controls, maintenance, and validation.

For a motor drive, the twin may include the inverter, motor, load, thermal path, cable behavior, sensor limits, and control logic. For a DC/DC converter, it may include switching behavior, magnetics, capacitor aging, semiconductor temperature, and load transients. For a grid converter, it may include plant controls, grid impedance, fault ride-through behavior, and power quality. In each case, the twin becomes valuable when it is tied to the operating modes and failure mechanisms that matter for the project.

Digital twins also improve testing. They can support virtual commissioning, hardware-in-the-loop test planning, what-if analysis, and accelerated exploration of abnormal conditions that are expensive or risky to reproduce on hardware. In field operation, the same model can help distinguish normal operating variation from developing degradation.

From offline models to production deployment

AI and digital twin adoption usually progresses in stages. Early use cases often run offline, where the risk is low and the goal is to accelerate engineering judgment. As confidence grows, the same models can support test automation, field diagnostics, or eventually bounded control assistance. Each step requires more validation, cybersecurity discipline, and operational ownership.

Design-stage acceleration

AI tools can summarize simulation data, rank candidate designs, estimate losses or temperatures, and guide engineers toward promising component and control choices before hardware is built.

Field monitoring and maintenance

In deployed systems, AI models can track drift in temperature, ripple, switching behavior, fault frequency, or sensor agreement, supporting condition-based maintenance and targeted troubleshooting.

Test-bench and validation support

Digital twins can compare expected and measured converter behavior during load steps, thermal tests, fault injection, and hardware-in-the-loop operation, helping teams find model or hardware mismatches earlier.

Bounded control assistance

AI may support adaptive tuning or optimization, but safety limits, deterministic fallback behavior, and conventional protection layers should remain clear. Closed-loop use requires much stronger evidence than advisory analytics.

Website: www.MarSumSolutions.com
Call Us: +1(937) 524-5114
Email: CustomerService@MarSumSolutions.com

High-value applications

AI and digital twins are most valuable where converter downtime, debug time, field failures, or inefficient operation are expensive. They are especially relevant in systems that already have rich telemetry and repeated operating patterns.

Industrial drives and smart factories

Motor drives, robotics, pumps, compressors, and process equipment generate useful electrical and mechanical signatures. AI and digital twins can support predictive maintenance, energy optimization, tuning, and faster root-cause analysis.

EVs, chargers, and transportation

Traction inverters, onboard chargers, DC/DC converters, and fast-charging systems operate across wide duty cycles. Model-based analytics can improve fault detection, thermal prediction, control tuning, and validation coverage.

Renewables, storage, and grid converters

Solar inverters, battery energy storage systems, and grid interfaces must operate reliably over long service life. Digital twins can support model validation, grid-code studies, power quality analysis, and condition-based maintenance.

Aerospace, defense, and critical systems

High-reliability converters need traceable validation and predictable behavior. AI may help with anomaly detection and design exploration, but outputs must be explainable, bounded, and compatible with safety and certification expectations.

Markets moving toward AI-enabled power electronics

Interest in AI for power electronics is rising because the technology addresses real pressure points: faster development cycles, higher power density, growing field data, reliability expectations, and increasingly software-defined control systems. Industry activity is also becoming more formal. The European Center for Power Electronics (ECPE) has launched a 40-organization task force preparing a white paper on Artificial Intelligence in Power Electronics, with attention to design, manufacturing, product operation, and training across the lifecycle.

Semiconductor and advanced manufacturing: Factory automation, robotics, precision motion, power supplies, and semiconductor tools create high-value opportunities for predictive maintenance, digital twins, and converter performance optimization.

Renewable energy and storage: Grid-connected converters and storage assets increasingly need validated models, reliable operation, and fast fault analysis. Digital twins can help connect design assumptions to field behavior over long service life.

Data centers and high-density power: AI computing facilities are pushing power density, thermal limits, and uptime requirements. AI-assisted design and digital twins can support converter optimization, monitoring, fault isolation, and capacity planning.

Integration challenges that determine project success

The hardest AI and digital twin problems usually appear at the boundary between power electronics engineering, software, data infrastructure, test, and operations. A useful model must be technically correct, connected to the right data, and trusted by the people who act on its recommendations.

Data quality and context

Converter data only matters when it is tied to operating mode, firmware version, hardware revision, sensor calibration, temperature, load condition, and event history. Without context, AI models can learn the wrong patterns.

Explainability and trust

Engineers and operators need to understand why a model recommends a control change, maintenance action, or design direction. Black-box outputs are difficult to use in high-reliability systems.

Cybersecurity and data governance

Connected converters, cloud analytics, and remote diagnostics expand the attack surface. Access control, secure updates, data ownership, and recovery procedures must be designed intentionally.

Physics-informed validation

Purely data-driven models can fail outside the training set. Power electronics AI should respect circuit behavior, thermal limits, device ratings, control constraints, and known failure mechanisms.

Real-time and embedded limits

Some AI functions must run with limited processor time, memory, latency, and deterministic fallback behavior. The deployment target matters as much as the algorithm.

Lifecycle maintenance

AI models and digital twins age as hardware, firmware, loads, and environments change. Model updates, version control, retraining, and validation should be part of the maintenance plan.

How MarSum supports AI and digital twin power electronics programs

MarSum Solutions supports high-performance power electronics, motor-drive, converter, controls, modeling, and system-integration programs with an engineering-first approach focused on performance, robustness, and manufacturability. AI and digital twin projects sit at the intersection of power-stage design, controls, sensors, thermal behavior, diagnostics, software, and validation, which is where early engineering decisions have the largest effect on project risk.

Our work can include digital twin architecture review, converter and motor-drive modeling support, data and diagnostics strategy, AI use-case definition, control and optimization review, hardware-in-the-loop and validation planning, predictive maintenance criteria, and integration support between power electronics, embedded software, and plant or product-level systems. We also help teams translate broad goals such as AI-enabled control, faster design exploration, predictive fault detection, and condition-based maintenance into testable engineering criteria.

For equipment suppliers, developers, and operators adopting AI or digital twin methods, the goal should be trusted engineering decision support rather than generic analytics. A disciplined system-level approach can reduce debug cycles, improve reliability insight, and support a faster path from experimental model to production-ready power electronics workflow.

Engagement models

We support customer teams through focused technical consulting, model and controls support, design reviews, validation planning, and deeper co-development efforts depending on program phase. Typical engagements range from early feasibility and requirements definition to prototype validation, field-debug support, digital twin development support, and production-readiness planning for AI-enabled power electronics systems.

Selected sources: ECPE AI in Power Electronics Task Force announcement; IEEE and industry digital twin publications; power electronics modeling, diagnostics, and validation literature.

Contact us today to scope your AI-enabled power electronics, digital twin, predictive maintenance, or converter optimization project!